University of Salford

School of the Built Environment

Doctor of the Built Environment (DBEnv)

Practice-based Research

Development of a management framework to improve the building services engineering design process; a case study of engineering management in an Irish consultancy practice

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ABSTRACT

The building services engineering (BSE) design process is a major source of problems at construction stage, even to the extent of undermining systematic management. Managerial practitioners have wrestled with this productivity gap for many years, and the time has come to innovate. The current approach to BSE management is inherently complex, which is exacerbated by the highly dynamic nature of the architectural, engineering and construction (AEC) industry in Ireland.

A critical literature review provides an academic overview of engineering management in BSE practice, and demonstrates how this managerial role influences the performance of activities during design stage, and its impact at construction stage. BSE management at these key junctures was further scrutinised by focusing on its relationship to people, processes and technology, by which a theoretical framework was established. Modern theory suggests that any unresolved issues at design stage must be resolved at construction stage, which consequently, initiate dysfunction in practice. Engineering management issues cannot be resolved by simply tightening the design process, achieving the same milestones with less information, but by systematically cultivating a skilful design team, embracing efficient processes and accelerating digitalisation.

Adapting a qualitative inquiry permitted the researcher to parallel the different components of the synthesised theory (theoretical framework) with triangulated data sourced from a cross-sectional instrumental case study using interviews, and supported by document analysis and the researcher's self-reflective journal. As the primary research method, structured, open-ended interviews were conducted with fifteen key professionals directly involved with delivering the case study project. An analysis of this practice-based research contributed to the development of a managerial framework, which is intended to improve the BSE design process, thus the basis for promoting a sustainable engineering practice during and after-design. The validity of this framework was also tested by conducting interviews with five seasoned BSE managing directors, who were judiciously chosen from five leading Irish BSE practices.

Scholarship in BSE consultancy practice is limited, particularly in engineering management, and although this inquiry is a means of advancing knowledge, it also serves as a disciplined and systematic procedure by shedding a new light on managerial effectiveness, whether or not the conclusion leads to popularism amongst peers. This academic inquiry draws on conventional wisdom of engineering management, and deals rigorously with the evidence to improve the design process by adapting a modern management approach to ensure that BSE practice consists of people with relevant education, skills and experience, who are committed to conducting staged processes throughout the project life by embracing digital engineering.

Furthermore, this doctoral thesis concludes that the adaptation of this managerial framework by BSE practices has the potential to enhance technical efficiency and operational effectiveness, thus sustaining a natural, social and built environment.

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GLOSSARY AND TERMS

Artificial intelligence *(AI) describes when a machine mimics human cognitive functions such as problem-solving, pattern recognition, and learning* (Constructible, 2020)

Augmented Reality *(AR) is a live direct or indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data.*

Axiology *deals with the nature of value of the research and inquires what is intrinsically worthwhile.*

Building Information Modelling *(BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of buildings and places with a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle* (GCCC, 2017).

Building Information Modelling Execution Plan *(BEP) explain how the information modelling aspects of a project will be carried out.*

Building Information Modelling Manager *is responsible for the implementation of BIM and the digital construction procedures at the design, construction and handover stages of a project.*

Building Services Engineering (BSE) *is the design of mechanical and electrical systems to provide safe and comfortable environs for occupants within and outside buildings.*

Building Services Research and Information Association *(BSRIA) is a test, instruments, research and consultancy organisation in construction and building services providing specialist support services for design, construction, facilities management, product testing and market intelligence.*

BuildingSMART International *(bSI) is the worldwide industry body driving the digital transformation of the built asset industry* (BuildingSMART, 2020).

Built Environment *is any man-made structure, feature, and facility viewed collectively as an environment in which people live and work, which is distinguished from the natural environment* (Schindler, 2015).

Commonality *in data analysis compares the frequency distribution of data between the interview participants to determine the proportion of common data values that one has that are also in the other.*

Construction-Operations Building information exchange *COBie is the setup and delivery of digital Facilities Management data during normal design and construction stages* (BIM Ireland, 2017)

Conceptual / Theoretical framework *is the system of concepts, assumptions, expectations, beliefs, and theories that the researcher holds about the phenomena being studied; a product that explains the main things to be studied and the presumed relationships amongst them* (Miles & Huberman, 1994). *Theoretical framework in a study is based on an existing theory whilst the conceptual framework is something the researcher can develop based on this theory.*

Constructivism *infers that researchers construct knowledge out of their experiences.*

Deductive research *relates to the deduction of particular instances from general inferences; it entails the development of a conceptual and theoretical structure which is then tested by observation.*

Design for Manufacture and Assembly *(DFMA) refers to the design of a product for ease of manufacture and for ease of assembly*

Design management *seeks to link design, innovation, technology, management and clients to provide competitive advantage across economic, social/cultural, and environmental factors. It is the art and science of empowering design to enhance collaboration and synergy between design and business to improve design effectiveness* (Design Management Institute, 2022)

Design team *comprises the various disciplines which collectively are responsible for translating client's requirements into information that describes the scale and shape of the building* (Portman, 2014).

Differences *in data analysis is a point or way in which participants' views or things are dissimilar.*

Digitalisation *is the act of changing practice processes through the use of digital technology.*

Digital Constructs *is the use and application of digital tools to improve the process of delivering and operating the built environment*

Digital engineering *is the art of creating, capturing and integrating data using a digital skill set.*

***Digital Ecosystem** is a group of interconnected IT resources that function as a unit* (Content Strategy, 2020)

***Digital Smart** is being connected, data-driven and making greater use of artificial intelligence*

***Empirical research** is a way of gaining knowledge by means of direct and indirect observation or experience rather than theory or pure logic.*

***Engineering design process** is a series of steps that engineers follow to come up with a solution to a problem*

***Engineering management** is the application of the practice of management to the practice of engineering*

***Epistemology** is the branch of philosophy that investigates what knowledge is and how it is acquired*

***Explicit knowledge** is knowledge that can be readily articulated, codified, accessed and verbalized that can be easily transmitted to others.*

***Immersive technology** allows a person to immerse themselves within an environment. Two of the main technologies used are Virtual Reality (VR) and Augmented Reality (AR)* (AECOM, 2018)

***Induction** is the general inference induced from particular instances, or the development of a theory from the observation of empirical reality.*

***Information and communication technology (ICT)** encompass all technologies for the communication of information, that is, any medium to record information, any technology for broadcasting information and communicating through voice, sound or images.*

***Instrumental case-study** is the study of a case to provide insight into a particular issue, redraw generalisations, and build theory* (Stake, 1995).

***Interpretivism** involves researchers to interpret elements of their study, thus integrating human interest into the study.*

***Mechanical, Electrical and Public Health engineering** (MEP) focuses on the mechanical, electrical and public health engineering disciplines needed to build safe, working structures for human use and occupation.*

***Multidisciplinary Team** (MDT) is composed of members from different professions with specialised skills and expertise. The members collaborate together to deliver a project to meet the client's expectation.*

***Ontological belief** reflects the researcher's interpretation about what constitutes a fact; the researcher's view of the nature of reality or being.*

***Paradigms** portray how the researcher sees the research topic through perception, understanding and interpretation* (Trafford & Leshem, 2012).

***Philosophical** relates to the study of the fundamental nature of knowledge, reality, and existence.*

***Positivism** is the view that the only authentic knowledge is scientific knowledge.*

***Practical reasoning** is the use of reason to decide how to act.*

***Practice-based Research** is an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice.*

***Pragmatism** research philosophy accepts concepts to be relevant only if they support action. Pragmatics recognise that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities.*

***Revit** is a BIM software that facilitates AEC professionals to design a building in 3-D with 2-D annotation of its inherent components.*

***Sustainability** is designing MEP systems that uses low-carbon, low-impact, non-toxic materials and recovers used resources.*

***Tacit knowledge** is knowledge that is difficult to transfer to another person by means of writing it down or verbalizing it.*

***Themes** in data analysis are features of participants' accounts characterising particular perceptions and/or experiences/things that the researcher sees as relevant to the research question.*

***Theoretical reasoning** is the use of reason to decide what to follow.*

***Virtual Reality** uses software-generated realistic images and sounds to replicate a real or imaginary setting that simulates a user's physical presence to enable them to interact with this space (AECOM, 2018).*

ACRONYMS

AECI Association of Consulting Engineers of Ireland

AI Artificial intelligence

AR Augmented Reality

BIM Building Information Modelling

BEP Building Information Modelling Execution Plan

BSE Building Services Engineering

BSRIA Building Services Research and Information Association

bSI BuildingSMART International

CDE Common Data Environment

COBie Construction-Operations Building information exchange

DFMA Design for Manufacture and Assembly

EI Enterprise Ireland

EIR Employer’s Information Requirements

GDP Global Domestic Product

ICT Information and communication technology

IOT Internet of Things

MEP Mechanical, Electrical and Public Health engineering

NBC National BIM Council of Ireland

Text All figures containing content highlighted in grey-and-blue infers direct relevance to the research topic

CHAPTER 1 INTRODUCTION

1.1 BUILDING SERVICES ENGINEERING PRACTICE

What was once deemed the province of a craftsman, building services engineering (BSE) now demands the services of a body of highly educated and specialist trained professional engineers (Portman, 2014). Building services engineers are responsible for the design of the mechanical, electrical and public health (MEP) systems required for the safe, comfortable and environmentally friendly operation of the building (Miller, Vandome, & McBrewster, 2009). This multidisciplinary field of engineering essentially brings buildings and places to life. The BSE design process is the design heart of the Irish AEC industry, and is defined by eight succinct principles: *dynamic nature of BSE systems*; *occupant subjectivity*, e*nd-user behaviour*, *design life expectancy*, *maintainability*, *energy consumption*, *design responsibility*, *and sequencing of the project team design process* (Portman, 2014).

The increasing complexity of modern Irish buildings has significantly increased the pressure on management to improve the performance of the design process. Thus far, research has identified that a large percentage of defects at construction stage arise through decisions or actions at the design stage, which by association, undermine its systematic management; *any unresolved design issues must be resolved at construction stage* (Mryyian & Tzortzopoulos, 2013). BSE practice is not a simple design-based process, but a complex integration of explicit and tacit knowledge-driven managerial and technical practitioners yearning a successful installation at construction stage (Sheppard, Colby, Macatangay, & Sullivan, 2006).

Poor communication, lack of adequate documentation, deficient or missing input information, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision-making have been identified as the main problems during the design process. This inherent productivity gap leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage (Yongping, Chunyan, Pengfei, & Weiping, 2014). Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in BSE consultancy practice. The small relative cost of the design process when compared to construction costs disguises the importance of BSE managerial effectiveness for the overall project performance (Austin, Baldwin, & Newton, 1994).

BSE design is a dynamic and complex process due to its multidisciplinary nature. It requires managerial and technical competence to ensure that MEP systems are safely designed, legislatively compliant, and more importantly, technically coordinated in an multidisciplinary environment. It is essential to recognise that this design process involves highly coordinated work, and success relies on effective engineering management to deliver a definitive design under project constraints, including, time, quality, cost and scope (Trevelyan, 2014).

Distinctions between disciplines in BSE practice often introduce boundaries, particularly between management and practitioners. With an increasing number of specialisms in the design process, there is a tendency for engineering practitioners to work in silos. Intrinsic multidisciplinary teamwork often generates problems when design is shared between several designer disciplines that do not always share the same knowledge and often have contradicting objectives designing a project, which provides further challenges for management (Yongping, Chunyan, Pengfei, & Weiping, 2014).

Effective engineering management demands that project requirements have been correctly interpreted in a mutually agreed brief, with a consistent format of technical verification and design analysis audit trail (Akbıyıklı & Eaton, 2011). This critical process is managed and performed in a series of iterative steps, which translates client aspirations into a series of technical documentation used to procure, manufacture, install, commission and operate the building elements and the project as a whole (Portman, 2014). This complex process alludes that BSE practice would benefit from investing heavily in adopting new technology, and training their practitioners to operate this technology efficiently.

According to the MacLeamy curve *(Figure 1)*, the majority of the workload and effort need to be shifted towards the mid-design stage, as opposed to the traditional integrated project delivery (IPD) approach, which tends to produce the design documentation at the end of the design stage. Sustaining the implementation of new technology requires extra effort from both management and practitioners, and their openness in delivering quality design in the format of transferable digital information (Hamil, 2012) (Walaseka & Barszczb, 2017). BSE management that adopt the Building Information Modelling (BIM) process, administer a greater effort by their practitioners during the early design phases of a project. BIM is gaining traction in Ireland, and with continued investment, focus and time initiated from a Government-led strategic agenda, practice management will be in a position to implement successfully (Engineers Ireland, 2019).

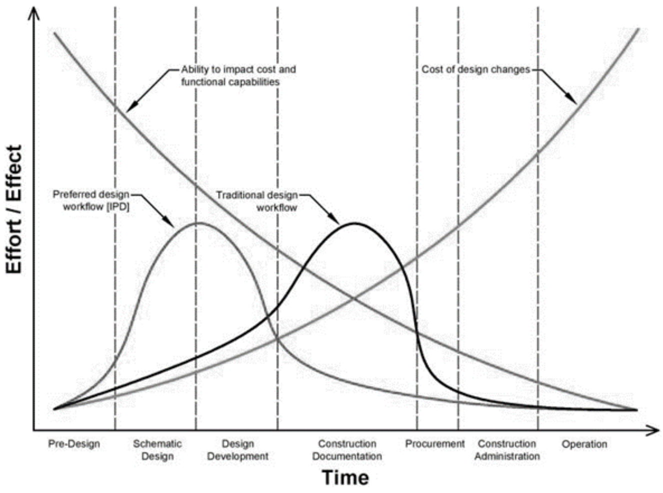

Figure 1 *Design workflow – The MacLeamy curve* (Walaseka & Barszczb, 2017)

More recently, there is a real need to design buildings faster and cheaper, which requires management and practitioners working together in a more concerted manner (Pheng & Hou, 2019). Management that embrace the BIM process strategically at design stage could be better positioned to effectively deliver a project successfully. However, its implementation success will lie in both cultural and technological change (McAuley, Hore, & West, 2012) (GCCC, 2017). BSE design is a difficult process to manage, and the full adoption of BIM would require effective planning and control to minimise the effects of complexity and uncertainty at construction stage.

Engineering management is an emergent professional discipline, which separates the management function of the design stage from the design function (Akbıyıklı & Eaton, 2011). This is particularly poignant in today's digital revolution in Ireland. Therefore, a workable design strategy is essential to exert managerial control over the design process (Austin, Baldwin, & Newton, 1994). Establishing matters of direction and control through effective engineering management channels is imperative to ensure deliverability and profitability in BSE practice. Despite great importance, less research time and effort has been dedicated to the management of the design process than that of construction management and project management (Austin, Baldwin, & Newton, 1994) (Kostela, Huovila, & Leinonen, 2002). Practice research in engineering management was initiated sixty years ago, but little or no research has been conducted in Irish BSE practice. The reason for this gap in research literature may be explained by the relatively few professional researchers who understand the language and concepts of engineering practice (Trevelyan, 2007).

There has been a considerable upheaval in Irish design-based practices, and consequently, the evolution of efficient engineering management concepts has suffered greatly by an incapacity for practices to present their challenges, and to fund imperative business development and engineering related skills, which are fundamental tenets for multidisciplinary collaborative design (Construction Industry Council, 2011). This situation has now paved the way towards transforming the design process, thus potentially securing competitiveness in the Architecture, Engineering and Construction (AEC) industry. This evolution requires BSE management and their multidisciplinary practitioners to work in a more collaborative manner, and change outdated design practices and adversarial approaches, and adopt new technologies and methodologies.

However, engineering practitioners generally do not like change and without a solid management process, they are more likely to maintain the status quo of poor design practices (Montague, 2015). Accordingly, the researcher has engaged in a process of critical reflection to draw upon critical perspectives (Rigg & Trehan, 2008), linking his learning and work experiences, to understand and conceivably change BSE practice by developing a managerial framework to improve the current design process. Reflection has gained legitimacy in recent times, particularly in terms of practice and professional development, and improves the depth and relevance of individual learning by looking back on experiences and learning to consciously frame the way management is interpreted (Moon, 1999). More importantly, the act of reflection has strengthened the researcher's consciousness, which is inspired by discrepancies in existing knowledge, skills and indeed practitioners' attitudes (Schon, 1983). This reflective process has facilitated scholarship through experience with theoretical and practice learning, thus forming a new knowledge base and potentially new behaviors amongst practitioners (Rigg & Trehan, 2008).

This research exposes the theoretical issues relating to *general* engineering management at design and construction stages, which required a well-disciplined literature review to synthesise its adaptability to BSE management. A theoretical framework evolved from that, and its components were tested from the findings on a practice-based case study, whereby the researcher was assigned the role of single-point-of-contact for the engineering and cost management teams. This role permitted the researcher an advantage to gain meaningful insight into the complex delivery process from briefing to operational stages (2014 – 2020) *(Figure 2).*

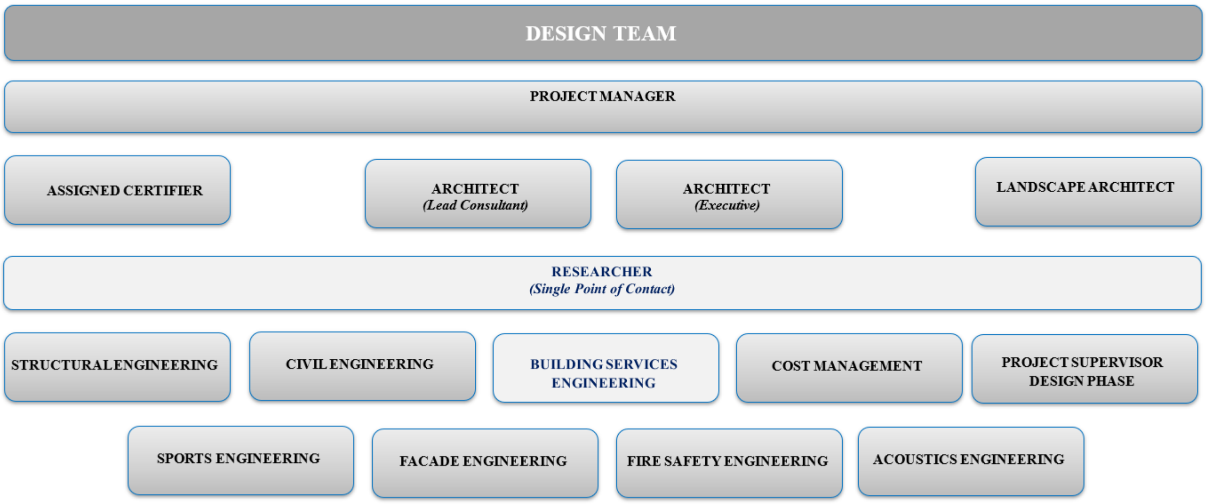

Figure 2 *Researcher's role on case study project*

The researcher recognises that findings drawn from one case study are limited, and therefore, strong parameters were established and clear research objectives were set from the outset of this inquiry (Yin, 1994). This empirical research also follows a well-established qualitative research method used by contemporary researchers in the built environment.

The researcher was cognisant of the importance of data triangulation from the outset of the data analysis, which is perceived to contribute to the inherent data saturation, thus enhancing the reliability of the research outcome. This inquiry takes the form of an *instrumental* case study, extending from the confines of the researcher's design practice to the greater construction team. This strategy primarily involved gathering data from fifteen open-ended structured *interviews* with project team members, which presented a cross-section of participants' responses. The researcher also used *document analysis* provided by the project team, and embraced a *self-reflective journal* to support the assumptions and aim of the research, and to clarify any subjectivity *(Figure 4).*

Theory informs thinking, which assisted the researcher in making these research decisions. By linking theory and research, the process of collecting data has a specific purpose, thus enabling the researcher to create and develop new theory regarding certain phenomena that previously had no satisfactory explanation. The research approach *(Chapter 3)* uses theory to make sense of the research topic (Trafford & Leshem, 2012), and how engineering management is portrayed through perceptions, understanding and interpretations; the paradigm (Kuhn, 1996). It is here that the theoretical framework has evolved, providing a theoretical overview of the research and order within the research process *(Figure 4).*

Interactions from literature, reflection and assumptions from the researcher's practice have generated such theories *(Figure 3).* The practical relevance of a theoretical framework enabled the researcher to impose a sense of reality, order and coherence in the context of BSE practice, whilst coming to terms with their experience (Cohen, Manion, & Morrison, 2000).

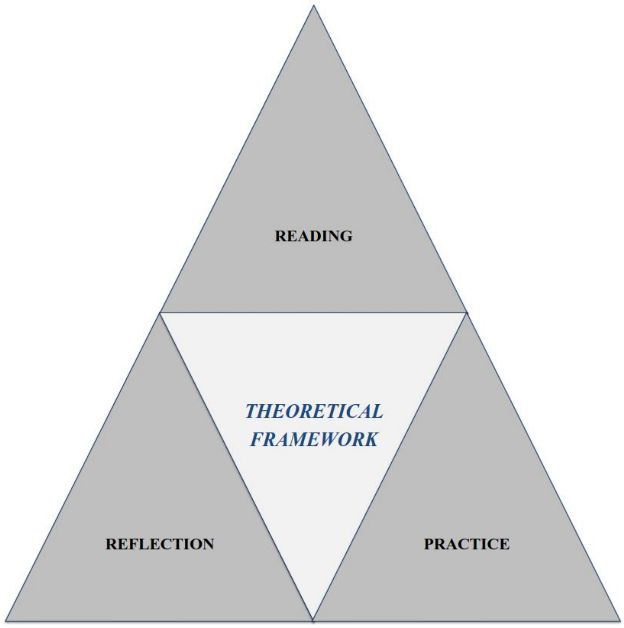

Figure 3 *Sources of theoretical frameworks* (Trafford & Leshem, 2012)

This inquiry establishes the relationship between the researcher and the researched, epistemological assumptions about the nature of knowledge with the legitimate knowers, the extent to which subjective meanings are valued and incorporated into the research, and how the researcher is incorporated into the process of analysis and presentation of findings (Berman, Ford-Gilboe, & Cambell, 1998). The methodological assumptions surmised articulates how the researcher has procured knowledge in a systematic manner driven by their ontological and epistemogical beliefs, which comprise of the research method with variant degrees of subjectivity and objectivity (Ratner, 2002).

This research favours *constructivism*, whereby the researcher constructs meaning based on interaction from their experience, through which knowledge is not found, but constructed, thus recognising the importance of subjectivity, but not rejecting the notion of objectivity. Equally *interpretivism* signifies that where a theory cannot be proven, a strong case can be made for it by disproving alternative explanations, and relies heavily on naturalistic methods of interviewing, observation and analysis of existing knowledge *(Figure 4)***.**

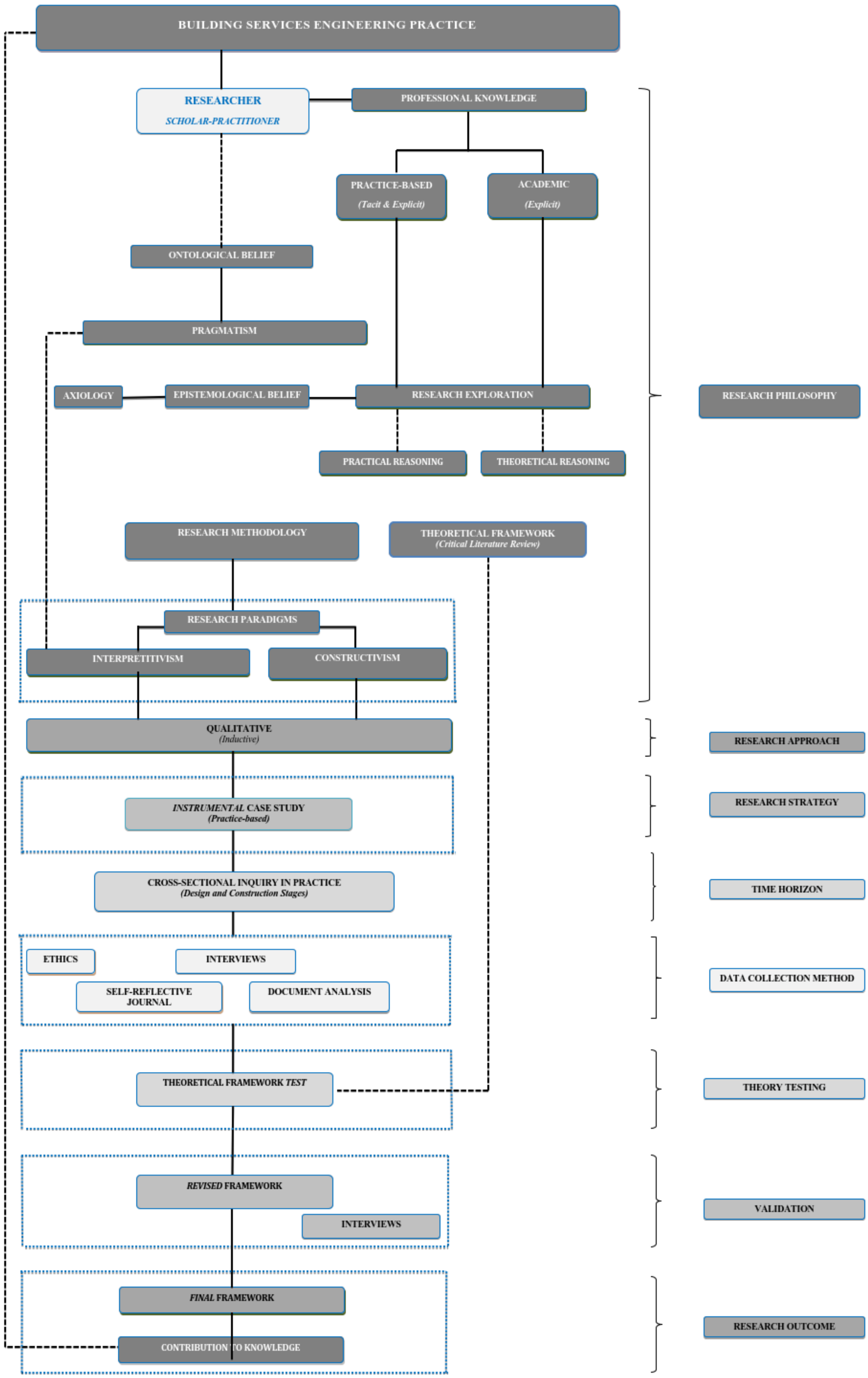

Figure 4 *Research process map for BSE management inquiry*

Methodologies justify methods, and methods produce knowledge, and therefore, the inherent methodologies have epistemic content (Carter & Little, 2007). By appropriating key research methodologies, a succinct research design was distilled for this inquiry, which permitted the researcher to parallel the different components of the synthesised theory *(theoretical framework)* with collected data *(Chapter 3 - Figure 39)*. This empirical review permitted the researcher to synthesise current theory and literature on engineering management, and parallel its meaning to the practice-based case study from manually analysed qualitative interview data. The adaptation of this research method produced a *revised* framework, whereby its validity was tested by conducting additional interviews with seasoned professionals from five leading Irish BSE consultancy practices.

More influentially, this research focused on a body of literature in engineering management in the context of *people*, *processes* and *technology* (PPT), which was synthesised to ascertain is theoretical adaptability to BSE management. The reason for this triangulated focus is that successful project implementation requires an approach that optimises the relationship between PPT. Ensuring that the BSE team consists of *people* with relevant education, skills and experience, who are committed to conducting staged *processes* throughout the project life, and supported by suitable *technologies* is imperative for effective practice management (Pee, 2009).

1.2 MANAGEMENT RESEARCH

The increasing dominance of management as a discipline within the built environment research community has been welcomed by the AEC industry (Chynoweth, 2009) (Amaratunga, Baldry, Sarshar, & Newton, 2002). However, the precise boundary of the managerial construct in the built environment is not fixed; it has been described as a range of practice-oriented subjects concerned with the design, development, and management of buildings and places (Griffiths, 2004). BSE management recognises that most projects go through difficult phases as they evolve from concept to operational. Given the level of intellectual investment made in practice, it is critical to understand why projects still go wrong from the inherent lack of management in practice.

Engineering practitioners respond to structure, and the provision of a well-defined BSE management framework to fully communicate a set of core principles could create alignment, increase understanding, and mobilise a team around a shared and common way of working.

People prefer certainty, well-defined boundaries and clarity of their role and responsibilities; practitioners operate more effectively when good performance is rewarded, and poor performance is challenged. The role of management at present is to signal change from stage to stage during a project's life cycle, and support their practitioners during this transition. With moves from design to construction stage, practitioner responsibilities change, and with this, tenure in the management role. Maintaining certainty by providing clarity remains paramount. Project delivery is not a democracy, it needs effective management with authority (Minns, 2019).

Ineffective engineering management at design stage results in inferior quality of installation, which often requires redesign, thus instigating practice dysfunction (Portman, 2014). Traditional managerial techniques are not well suited to modern BSE practice. A major challenge for management is understanding that design issues cannot be resolved by squeezing the design process, achieving milestones with less information or making explicit decisions to improve the design process (Portman, 2014).

Thus far, there is considerable disorder in design-based practices, particularly where activities are shared between several design disciplines that do not always share the same knowledge, and often have contradicting objectives designing a project. This research anticipates that effective management can potentially alleviate such ill-definedness and complexities, which can surface as a lack of information or the need for integrating multiple knowledge domains (Prudhomme, Boujut, & Brissaud, 2003) (Simon, 1977).

1.3 RESEARCH JUSTIFICATION

The built environment is well established as a recognised field of study by the international academic community. There is broad acceptance that this field is multidisciplinary, but there has been little attempt to define the cognitive nature of its particular knowledge base, nor to consider its implications for research (Chynoweth, 2009). Indeed, managerial research is rare in the BSE field, with an insignificant attempt to understand its underlying academic base. The current literature on engineering management tends to encompass BSE with other disciplines such as architecture, and more worryingly, does not recognise its unique features and idiosyncrasies (Portman, 2014).

The reason for this academic gap in the literature may be explained by the relatively small number of professional researchers who understand BSE practice (Trevelyan, 2007). Practice-based inquiry is an increasingly important field of research, which has a significant contribution to make to decisions about management knowledge and skill development of current and future practitioners (Figueiredo & Williams, 2013).

Fragmentation of multidisciplinary teams who have different responsibilities and objectives often generate managerial problems when design is shared (Mitchell, Frame, & Coday, 2011). (Yongping, Chunyan, Pengfei, & Weiping, 2014). This peculiarity is wholly evident in BSE practice, whereby deficiencies at construction stage arise through inefficient actions at design stage (Cornick, 1991). However, no comprehensive inquiry has been conducted to gauge this correlation in Irish practice notwithstanding the fact that 75% of the problems encountered at construction stage are generated from the design process (Mendelsohn, 1997). The dysfunctional impact on design practice is rarely understood, but it is estimated that an additional 40-50% of the total work hours is required to rectify such deficiencies (Kostela, Huovila, & Leinonen, 2002).

The relationship between management and practice dysfunction is understood, but there is little empirical evidence that quantifies such a linkage. Hence, the researcher is motivated by the obvious importance for a distinct management framework to deliver more value in practice. What has emerged from this inquiry is different to that presented in most engineering educational textbooks, which tend to view engineering practice as being exclusively made up of design or technical problem-solving. By contrast, this practice-based research presents a rather more complex portrait of engineering practice, where the management and technical aspects are inextricably interlinked (Figueiredo & Williams, 2013). This is rarely cited in contemporary literature on managerial research, partly because the language of discourse is often technical, and therefore, it can be difficult for outsiders to understand (Trevelyan, 2009). Previous research has focused principally on design planning and controlling change, the control of design activities and managing the integration of design teams and collaborative working at design stage (Akbıyıklı & Eaton, 2011). Very few observations have been reported on the actual work performed in BSE practice.

By contrast, numerous processes in engineering practice such as design management and project management have been extensively studied in an individual context, yet engineering management has scarcely received attention (Trevelyan, 2007).

However, this research contextualises engineering management knowledge in Irish practice. This research has also instilled intellectual confidence, independent development thinking, enthusiasm and commitment, and an ability to adapt effectively in the changing nature of practice *(Davis, Savage, & Miller, 2009)*. As an autonomous researching professional *(Deniclo & Park, 2010)*, this inquiry has permitted the researcher to contribute to knowledge in their profession, and to develop of a management framework to improve the design process in practice, thus the basis for promoting a sustainable engineering process during and after-design. The findings have provided useful insights, implications and recommendations for BSE practices alike. As far as the researcher is aware, this inquiry is the first of its kind in Ireland.

1.4 RESEARCH AIM AND OBJECTIVES

Engineering practice traditionally sought expert advice from management institutes, often regarding aspects of *people* behavior (Cardiff University, 2016). The results are normally disappointing as such institutes have limited insight and understanding of the *processes* and *technology* dimensions in BSE practice (Trevelyan, 2014). The increasing number of specialisms in the BSE design process creates a tendency for practitioners to work in silos, which provides challenges for management (Portman, 2014). The team often comprises of practitioners with different backgrounds and varying experience and education, and each with their lexicon of acronyms, methodologies, techniques, templates and ways of working.

This research proposes that BSE management who ensure that their team consists of *people* with relevant education, skills and experience, who are committed to conducting staged *processes* throughout the project life, and supported by suitable *technology* will innovate practice, and dramatically improving the efficiency and quality of the design process.

The aim of this research is to develop a management framework to improve the BSE design process by the proficient convergence of people, processes and technology in practice. In this regard, a number of justifiable objectives and respective methods were implemented to achieve the aim hereon (*Figure 5)* .

NR	OBJECTIVE	METHOD
I	Synthesis of BSE management theory	Conduct a literature review of design management and project management to provide a theoretical overview of engineering management
II	Develop a theoretical management framework	Conduct a literature review to exemplify how engineering management can improve the BSE design process by the efficient convergence of people, processes and technology, and its dichotomy at design and construction stages
III	Examine and test components of the theoretical management framework with empirical data to devise a revised framework	Conduct a cross-sectional instrumental case study of a practice-based project to gain insight to real engineering management at both design and construction stages. Empirical data principally sourced and analysed from interviews with 15-BSE professionals, and supplemented by case study project documentation, and the researcher's reflective journal
IV	Test the validity of the revised framework with empirical data	Test components of the revised framework with empirical data sourced and analysed from interviews with 5-seasoned professionals in the Irish BSE industry
V	Extrapolate a conclusive BSE management framework	The interpretivism paradigm is adopted to put data analysis in context, where the researcher has relied heavily on interviewing, observation and analysis of existing knowledge

Figure 5 *Research objectives with methods*

CHAPTER 2 LITERATURE REVIEW

2.1 PRACTICE-BASED RESEARCH

The built environment infers the unnatural surroundings, which provide a setting for human activity, extending from buildings and parks to neighborhoods and cities. By association, current theory recognises that the modern built environment is a multidisciplinary field, whereby its *design*, development, construction, operational management is an interrelated whole, whilst simultaneously ancillary with human activities over the course of time (Conte, 2018).

Although the built environment discipline is generally not regarded as a traditional profession or academic discipline in its own right, it draws upon a diverse collection of fields of study and practice-based subjects (Kehily, 2012). As individual subjects, they are deemed miniature, but together make up a universe as a whole encompassing, *management-oriented, design-oriented, technology-oriented*, business-oriented, public policy-oriented and traditional academic fields (Griffiths, 2004). The three former tenets primarily encompass design and research, which undoubtedly represent the key stages in production and evolution of the built environment**.** Such studies provide useful context, whereby facets such as *engineering management* research can be synthesised, providing a natural commonality to the field of design and innovation (Penn, 2008).

The creation and interpretation of *new* knowledge, through original research or other advanced scholarship extends to the leading edge of the built environment disciplines (Chynoweth, 2013). Making practical use of new concepts and ideas other than those embedded in well-established professional traditions requires intellectual effort. This can be challenging as research demands significant reflection, a consideration seldom adopted in the pertinacity of the built environment professional practice. By association, BSE management is now in a unique position to merge with the knowledge-creation community, which has the potential to improve productivity in practice, either by realising research findings or facilitating innovation (Eraut, 1985). However, BSE practice is not simply a design-based process, but a complex integration of tacit and explicit knowledge of both management and technical practitioners (Sheppard, Colby, Macatangay, & Sullivan, 2006). The subjective and objective evidence presented in this research facilitates the externalisation of such tacit knowledge to explicit knowledge.

There has been significant growth in the engagement of education with practice development. Research in practice and current literature indicates a growing superiority in the way that practice-based learning is being theorised and facilitated in higher education as a distinct field of practice and study supported by relevant androgogies and concepts of curriculum, which develops practitioners' capabilities by supporting their personal development and maintaining academic validity (Lester & Costley, 2010). However, this trend needs to be increased substantially to sustain practice in a competitive built environment. Consequently, higher education institutes are encouraged to increase their involvement in practice development, thus engaging with a wider range of practitioner learners (Leitch, 2006).

Whilst technical, professional and administrative abilities remain important, interventions that develop specialised practice skills and convey inherent knowledge have a diminishing lifespan as the repertoire of abilities needed by management continues to change and expand. From a socioeconomic perspective, it is inadequate and inefficient to focus on upskilling at a purely instrumental level. There is a fundamental need for management to develop abilities they require for their current and future practice. Management need to take more responsibility within practice and their careers to initiate self-managing practitioners and self-directed learners. The traditional view of management being qualified to apply a relatively well-defined body of knowledge and skills to practice is increasingly out-of-date, which infers that there is a greater role for the higher education sector in practice learning and practitioner development (Billett, 2010).

Admittedly, valuable practice learning often occurs through the medium of work in response to specific workplace issues, as opposed to formal education (Eraut, et al., 2005). Whilst this learning can be purely instrumental, it can be highly developmental, particularly when it is linked to a personally-valued purpose and engaged critically and reflectively. Henceforth, there is a trend within higher education institutes to move into practice territory to enhance and accredit work-based learning (Scott, Lunt, & Thorne, 2004). Practice-based learning is strongly research-informed, where management apply androgogical research to inform their practice (Griffiths, 2004). Their mastery of propositional knowledge ultimately demonstrates practice competence, where the focus is concerned with learners' reasoning and critical reflection, how they develop their capability in management and management research, and how they make critical judgements in practice (Brodie & Irving, 2007). The enhancement of practice-based learning and other experience-based sources draws on well-established theoretical underpinnings.

Most notably, where reflective management philosophy and practice-based learning draws on action research, participative inquiry and soft systems methodology are concerned with changing practice through collaborative means as much as researching them (Lewin, 1946) (Checkland, 1981); learners can develop insights through embarking upon real practice issues (Lester & Costley, 2010). The epistemological base of practice-based learning is rooted in a form of pragmatism in the philosophical sense that emphasises the interdependency of *knowing* and *doing*, coupled with a constructivist and to some extent phenomenological perspective in which the researcher is regarded as an autonomous self, who is making sense of their role through active participation (Dewey, 1938) (Tennant, 2004). The notion of constructivism, where knowing and doing coexist in a spiral of activity, where knowledge informs practice to generate further knowledge that in turn leads to changes in practice (Schon, 1987). Moreover, the concept of multidisciplinary knowledge being modified through questioning insight to produce new, practical knowledge through engaging with live practice issues, instigating a form of meta-learning, whereby the researcher can be seen as engaging in post-formal development and developing towards epistemic justification (Czikszentmihalyi & Rathunde, 1990).

A true understanding of how management and academics view the changing nature of practice highlights both challenges and opportunities *(Davis, Savage, & Miller, 2009)*, and has paved the way for academic inflation in recent times. This research focuses on a body of literature in engineering management from a *people, processes* and *technology* (PPT) perspective at design and construction stages, which was strategically synthesised to contextualise engineering management knowledge in Irish BSE practice *(Figure 6)*. The reason for this triangulated focus is that successful project implementation requires a management approach that optimises the relationship between PPT. Developing an appreciation for the theoretical dichotomy of the design-construction interface from a BSE management perspective is a fundamental tenet in this research. This review was by no means exhaustive, but serves to demonstrate the fragmented nature and complexity of the researcher’s discipline.

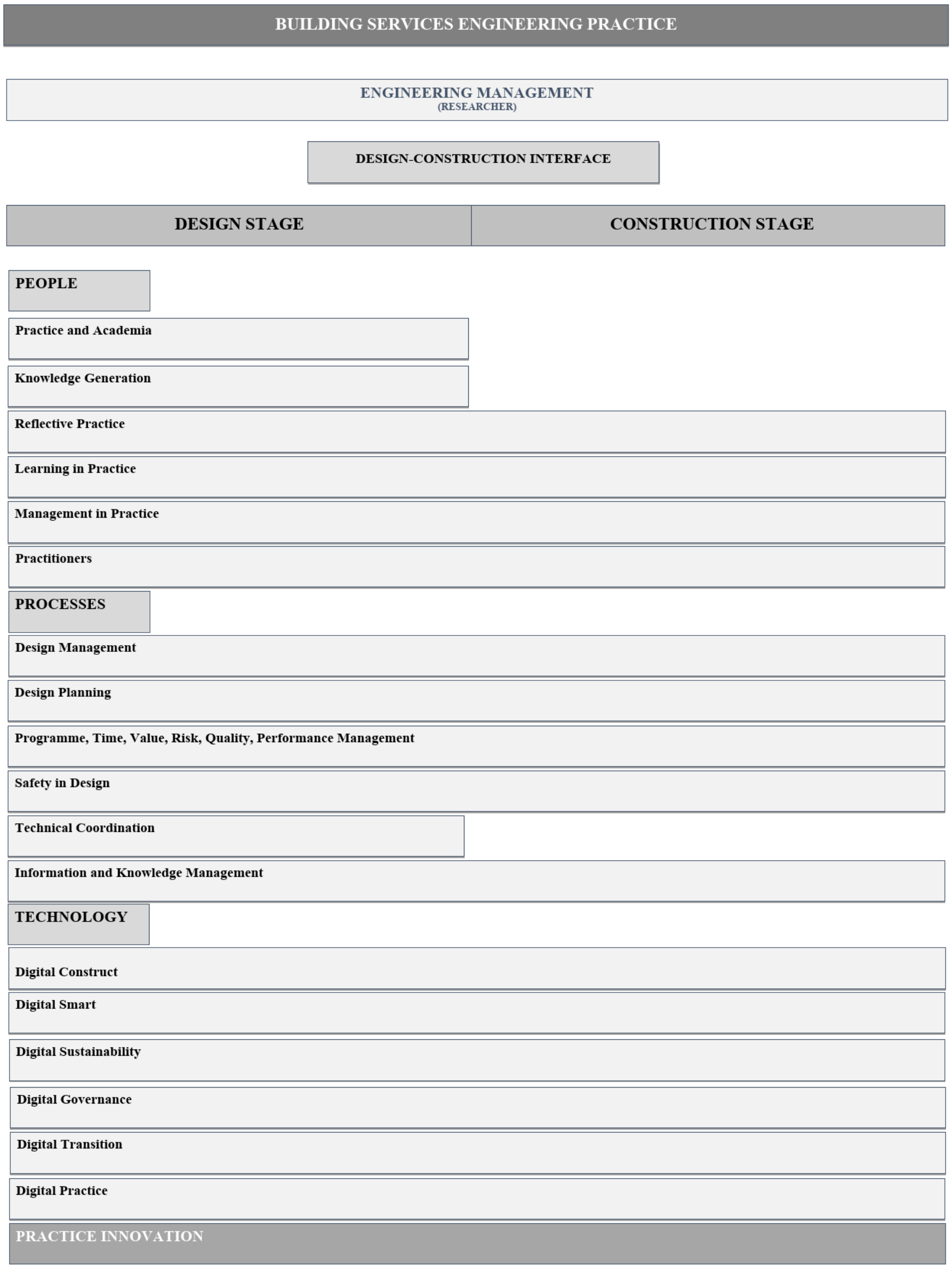

Figure 6 *Literature review scope*

2.2 ENGINEERING PRACTICE

Professional practice in engineering and education share a common set of tenets. They provide a worthwhile service in the pursuit of important human and social ends; embracing fundamental knowledge and skills, learning from experience, thus making judgments under conditions of uncertainty (Sheppard, Colby, Macatangay, & Sullivan, 2006). In general, engineering practice is often described as the application of theory and principles of science and mathematics to research concerning the development of economical solutions to technical problems.

More succinctly, engineering practice is the link between perceived social needs and commercial and technical applications, which does not only realise a certain degree of intellectual and technical mastery, but acquires the practical wisdom that brings together the knowledge and skills in a way that best serves a particular purpose for the good of humanity (Sheppard, Colby, Macatangay, & Sullivan, 2006).

Engineering practitioners spend their time dealing mostly with practical problems to encourage a design approach that challenges assumptions, thus enhancing their professional knowledge. They depend on what they know (Vincenti, 1990). *Knowing-how* and *knowing-that* distinctions suggests that engineering practice relies on managerialism to administrate planned knowledge (*knowing-why)* and strategic knowledge (*knowing-when)* to their practitioners, where it is applied, and how it applies (Shavelson & Huang, 2003). Their collective knowledge brings to bear *knowing-how* to perform tasks, knowing facts, and *knowing-when* and *how* to engage these tasks and facts to a particular problem.

Managerial and technical knowledge in engineering practice is dynamic, and often demands practitioners to continually learn over time by accommodating new knowledge, while retaining previously learned experiences (Parisi, Kemker, Part, Kanan, & Wermter, 2017). More importantly, the collective understanding of the built environment continues to change, and is becoming more comprehensive, complex and complete. This infers that practitioners need to stay informed of new and emerging knowledge (Engineers Ireland, 2016). The knowledge that practitioners draw from is continually expanding and evolving. If practitioners are reflective, alert and methodical in practice, they add to their tacit and conceptual understanding of how the design process works in an engineering design setting (Sheppard, Colby, Macatangay, & Sullivan, 2006).

Engineering practice is not simply a problem-solving process with specialised knowledge. It is the complex, thoughtful and intentional integration of design towards a meaningful end at operational stage. Nevertheless, practitioners have a tendency to search past experiences to find knowledge that has proved useful, and adapt managerial and technical features to their current design process even to the extent that these features depart from what has worked in the past (Sheppard, Colby, Macatangay, & Sullivan, 2006). Today, competent management of the design process demands a balanced mandate with creative and technical *people* who understand its analytic *processes* and their empowerment to foster appropriate *technology* – a managerial framework for making sense of this complex process.

2.3 DESIGN-CONSTRUCTION INTERFACE

When the design is complete, it does not necessarily mean that the construction stage will proceed smoothly (Portman, 2016), whereby suboptimal design solutions and the lack of installability often become apparent (Jiang, Solnosky, & Leicht, 2013). Rectifying these issues go beyond design rework, which generally instigate programme delays, higher cost, increase claims and disputes leading to higher maintenance cost. This scenario reflects badly on BSE management's capability and competency (Barshop, 2013), and can bare both financial and reputational cost to practice. The BSE package is often the largest individual subcontract with an installation value of typically 30-60% of the construction cost of a building (Hawkins, 2011), which needs to be value managed and controlled to optimise delivery of the project without compromising the quality of design, reliability and performance of goals (Pennypacker, 2005). Construction is a multifarious process with design deliverables being dependent on the form of contract deployed. By implication, BSE management need to recognise this idiosyncrasy for successful project delivery (Brown, Wendy, & Reilly, 2019).

Design and construction process theory suggest significantly different progressions, where design is perceived as being generally *iterative* and *cyclical* in nature, and construction as being *linear* and *sequential* (Austin, Baldwin, Li, & Waskett, 1999) (Koskela, 2000). These contrasting cyclical and linear characteristics make the imperative design-construction interface complex to manage (Frame, Coday, & Hoxley, 2011). The lack of sound scientific or theoretical foundations hinders the AEC's industry's ability to innovate, and to draw from other industries and other industrial processes (Koskela & Vrijhoef, 2001).

Each decision sequence at design stage consists of analysis, synthesis, appraisal, and decision, which reflects its cyclical nature (Mitchell, Frame, & Coday, 2011). While the design process is one of refining solutions to a set of problems and reducing uncertainties, construction is the creation of a product and must close out all uncertainties, including those that devolved to it from the design process (Lawson, 1997). This introduces the perception that the design process progressively eliminates uncertainties over time (Darke, 1979) *(Figure 7).* This dichotomy impacts the flow of work and information between the design-construction interface processes (Mitchell, Frame, & Coday, 2011), and may be the root cause of problems that beset Irish BSE practice.

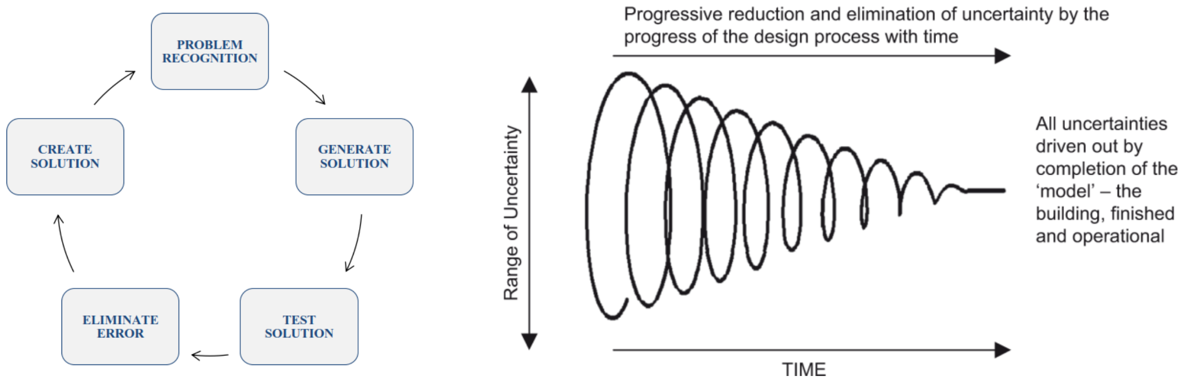

Figure 7 *The design process as an iterative-spiral cycle* (Brawne, 2003) (Darke, 1979)

The design-construction interface is especially important since the quality of the construction is generally a function of the quality of the information generated at design stage. Discords at this interface, which either results in delay in project duration, or compromise on quality or increase in cost, propels the need for effective management. Interface issues lead to low productivity, poor quality, waste, delays, claims, and cost overruns, which significantly lower the overall project performance, and implicitly, hinder construction progression (Sugumaran & Lavanya, 2013). Notwithstanding specialist contractors creating problems of their own, the literature infers that 75% of problems encountered during construction stage are generated during the design process (Sugumaran & Lavanya, 2013).

The extent to which documentation incompleteness affects construction is well-recorded in a plethora of anecdotes and data detailing inefficiencies leading to interpretation problems (Florence & Pryke, 2009). Indeed the obstinate nature of project team disciplines can also result in poor delivery performance compounded with a lack of data and incomplete building plans result in misinterpretation of the actual requirements, which ultimately leads to installability issues (Sugumaran & Lavanya, 2013).

In general, management has strong incentives to support the continuity, quality and intent of the design to limit potential risks, and moreover, achieve recognition for the quality of their design. In considering ways to reduce deficiencies on site, it is prudent to focus on practice, as it is that which that has the potential to eliminate inefficiencies at design stage.

2.4 ENGINEERING MANAGEMENT

Engineering management is the application of engineering principles to business practice (Koskela, Howard, Ballard, & Tommelein, 2002). It is an emergent professional discipline, which separates the management function of the methodical design process from the design function, and brings together the technological problem-solving savvy of engineering, administrative and planning abilities to oversee design and construction stages (Akbıyıklı & Eaton, 2011). Managing a process, where practitioners understand how they can minimise inefficiencies, and where management's greatest concern is ironing out minor design imperfections is seldom the case (Oehmen, 2012). However, inefficiencies in the design process do not arise primarily from technical intricacy, but from the managerial complexity, where managing the interactions between the different disciplines imposes challenges (Yassine, Falkenburg, & Chelst, 1999).

Design is undoubtedly a difficult process to manage and commands effective planning and control to minimise the effects of complexity and uncertainty at construction stage. The multidisciplinary nature of the BSE practice is typically serial and non-collaborative, where inherent inefficiencies at design stage lead to deficiencies at the construction stage, and consequently, dysfunction in practice (Murphy, 2002). The BSE design package is normally the largest subcontract on building projects, and is distinguishable by the degree of specialist design required and extent of interface with third parties (Portman, 2016). As the design process is becoming more multifaceted with the emergence of new disciplines in the built environment, new work practice is desirable by the implementation of a modern management framework, which makes better use of management their practitioners, knowledge and technology.

Indeed the complexity of modern MEP systems often requires design input from trade contractors during the design stage to appraise installability *(Figure 8).* This inference suggests that a cross-party design effort exists, whereby BSE practitioners, inspired by a conceptual mind, and contractors, motivated by a concrete mind, in the pursuit to achieve a successful delivery at design and construction stages (Sugumaran & Lavanya, 2013). Decisions made during the design process are multi-dimensional combining factors ranging from the highly subjective to the perfectly objective (Akbıyıklı & Eaton, 2011), and are a direct function of the construction stage (Rezaei, Çelik, & Baalousha, 2011).

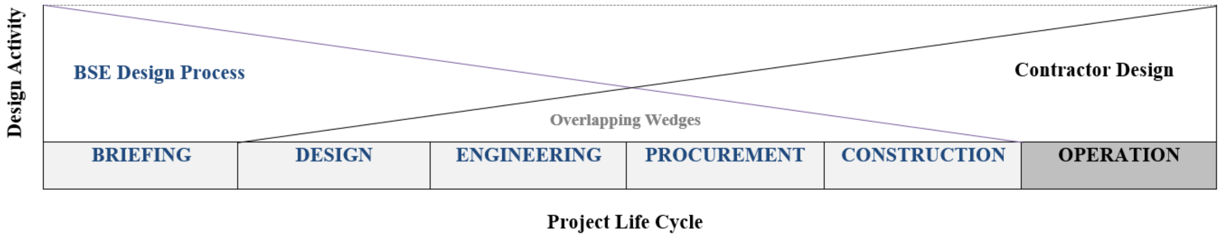

Figure 8 *BSE-Contractor Design Input* (Akbıyıklı & Eaton, 2011)

Design complexity is normally managed by decomposing the design process into smaller tasks and the assignment of these tasks to practitioners, reducing the risk and magnitude of iteration between design tasks (Yassine, Falkenburg, & Chelst, 1999), and exerting managerial control over the design process by understanding the intrinsic relationship between people, processes and technology (Austin, Baldwin, & Newton, 1994).

Engineering management also advocates the business side of design, aiming to create the right practice environment to control and support a culture of creativity and innovation, and to embrace the iterative nature of design involving multidisciplinary team knowledge to deliver design solutions in an ethically sound manner (Portman, 2014). Thus, a distinct management framework also has the potential to provide a competitive advantage across the economic, social and cultural, and environmental perspectives; a managerial approach to improve design effectiveness to enhance collaboration and synergy between design and business (Design Management Institute, 2016).

2.4.1 PEOPLE

2.4.1.1 PRACTICE AND ACADEMIA

Traditionally, education and training of BSE management is based on the natural and applied sciences, which tend to create people with *black-and-white* or *right-and-wrong* thinking. This rationale works well when dealing with technical design alone, but has its shortcomings when managing people in a technical multidisciplinary practice. Unlike design, people display unpredictable behaviour. An unsatisfactory interaction between people and their technical know-how is one of the greatest challenges facing engineering management (Portman, 2014). Education must reflect practice if it intends to prepare and attract competent managers.

Conversely, feedback from engineering practice could also support educators explain the relevance of curricula to students in acquiring cognitive and practical skills, and provide an appropriate motivation for learning (Trevelyan, 2007). As society deals with political, social, economic and technological changes, education often needs to be redefined, and by association, practice needs to be reformed (Sheppard, Colby, Macatangay, & Sullivan, 2006).

Practice demands its management to acquire of a body of specialised knowledge, problem-solving skills, and good judgment. These three domains of engineering education are aimed at establishing people who are intellectually trained, practically adept, and ethically responsible for their work. (Trevelyan, 2007). However, the effort by the Irish educational system to integrate these domains with a sense of professional and personal responsibility is blurred. It is imperative that practice management keep abreast of the digital knowledge-base through continuing professional development (CPD). As the *half-life* of practice becomes outdated, management who do not engage their practice with CPD may rely on outmoded knowledge (Engineers Ireland, 2016). There is also a need to recognise and value non-formal learning in a creative and innovative manner, thus raising the visibility of management skills acquired outside the formal system to foster amid complementarities (Soares, 2013).

Challenging theoretical, technical and contractual-based subjects in the Irish education system is without question essential to allow undergraduates and future managers achieve a high level of academic based-knowledge. Although this theoretical stance is relative and respected, educators often lack the connection between the classroom and the real engineering world (Laksov, 2018). To bridge this gap, it may be prudent to introduce sub-modules to focus solely on practical issues in *real* project matters, and taught by knowledgeable practice management with a sound academic background. Bringing field experience to universities could be provided by means of interactive discussions with other design and management disciplines in the AEC industry, and make the classroom an interactive environment by challenging undergraduates to open-up and be more vocal (Arthurs & Templeton, 2009). However, a true understanding of how management and academics view the changing nature of the design process highlights both challenges and opportunities *(Davis, Savage, & Miller, 2009),* and has paved the way for academic inflation in recent times.

2.4.1.2 KNOWLEDGE GENERATION

In its basic form, knowledge infers knowing something with familiarity gained through experience. By affiliation, *academic knowledge* is created by scholars and experts in their field, whilst *professional knowledge* is created by combining subject matter expertise with pedagogical knowledge (Kehily, 2012). Philosophers generally describe knowledge into categories; *personal*, *procedural* and *propositional*. The key to unlapping new knowledge is through practice reflection, recollection and anecdotal evidence (Mann, 2013). It is proposed that knowledge generated from this inquiry is better served by an approach that combines the strengths of both academia and professional practice.

The theory-practice community place different valuations on different kinds of knowledge (Eraut, 1985). Whilst being mindful of the conservative nature of many higher education institutes, knowledge quality may only be achieved by remodelling *tacit* knowledge into *explicit* knowledge through reflection. Once this process is demonstrated theoretically and methodologically, it can deliver legitimate academic knowledge (Chynoweth, 2012), which must be managed as a strategic asset, and shared amongst academia and practice.

The tacitness of knowledge resides within the human brain and is based on common sense. It constitutes understanding, capabilities and skills, which are accumulated by past experiences, and expressed in the form of thoughts, points of view, evaluations and advice, which is subjective in nature (Pathirage, 2014). It conveys the *know-how* in practice. On the contrary, explicit knowledge is based on academic understanding, which is gained through systematic nature of formal education, and conveys the *know-what* in the form of written expressions and constitutes a *people-to-document* approach. Thus far, acquiring and applying tacit and explicit knowledge is an individualist consideration, which would assume that few disciplines handle such knowledge inventories effectively (Smith, 2001).

An inherent shortcoming in generating new knowledge in BSE practice paves the way for innovativeness by emanating explicit knowledge through tacitness, which has the potential to separate the master from the common (Haldin-Herrgard, 2000). Although time consuming and problematic, the conversion of this knowledge is a critical prerequisite in this research *(Figures 9 & 10).*

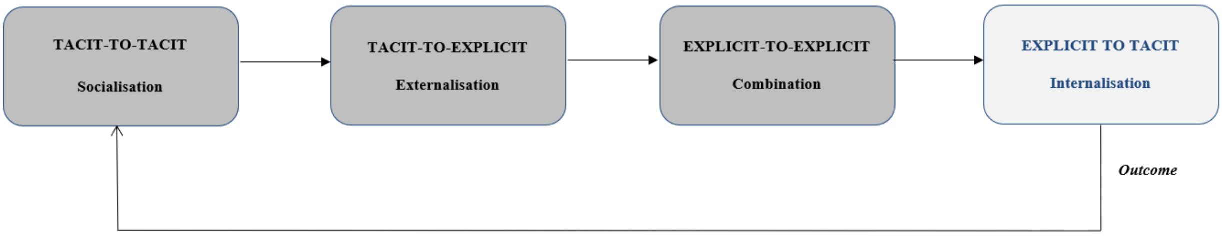

Figure 9 *Creating knowledge (Nonaka & Takeuchi, 1995)*

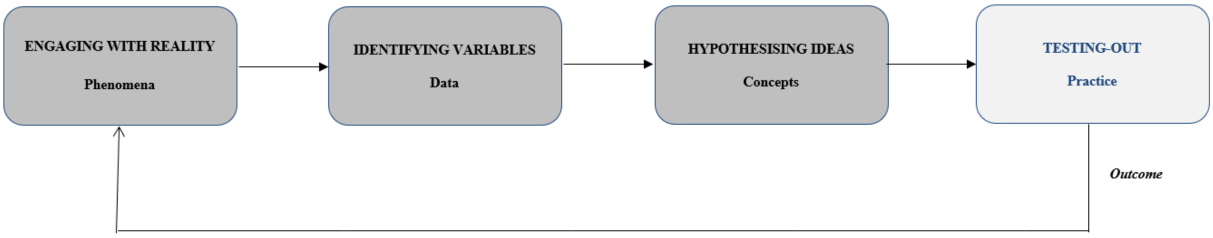

Figure 10 *Researching professional practice (Mann, 2014)*

2.4.1.3 REFLECTIVE PRACTICE

Reflection captures experiences, which is important in learning(Boud, Keogh, & Walker, 1985). It is described as a future-oriented yet retrospective process that encompasses a review of experiences, a critical analysis of causes and effects that lead to new understandings and appreciations, and draw of conclusions to guide future action and behaviour (Boud, 2001). Reflection in practice represents an activity pursued with intent and consciousness. Management must call on cognitive and affective skills to perform a reflection process. These skills include self-awareness and the ability to describe thoughts and feelings, critically analyse experiences, and develop new perspectives (Murphy & Atkins, 1993). It is a crucial process in transforming experience into knowledge, and essential for practice improvement. Albeit unconscious reflection occurs naturally, it tends to be unfocused and unsystematic.

Moreover, when the reflection process is brought into consciousness, intelligent evaluation and decisions may be made by management. The process of reflective conversation in practice advocates a model when managerial research is paralleled by Schon's study of the professions (Morgan, 1983) *(Figure 8)*. Reflection is unlikely to occur in familiar situations that allow management to automatically apply routine work practices; *nothing grows in a comfort zone*.

In contrast, new or unexpected situations trigger reflective learning processes, affording management the chance to acquire new knowledge (Mann, Gordan , & Mac Leod, 2009). Thus, reflection enables management to exploit learning opportunities, foster the acquisition of experiential knowledge and the development of their professional competencies (Gartmeler, Bauer, Gruber, & Heid, 2008).

The thinking process amongst management is one of the most important issues in managerial research (Stempfle & Badke-Schaub, 2002). Reflection is a crucial part of this process by transforming experience into knowledge, which is essential for evolving professional practice. When the reflection process is brought into consciousness, intelligent evaluation and decisions may be made. The reflective aspect of practice has acknowledged engineering management inventing a *rationality* to solve problems (Schon, 1983). Management copes with uncertainty, complexity, instability and uniqueness that is perceived as reflection-in-action (Schon, 1983). This inquiry appraises BSE management by *reflection-in-action* to identify inefficiencies at design stage and by *reflection-on-action* to recognise deficiencies at construction stages. Their negative impact on design practice *(planning)* is reviewed with measures proposed to mitigate practice dysfunction *(plan to action) (Figure 11).*

According to this model, problem solving is a manipulation of available *processes* to achieve chosen ends in the face of manageable constraints (Trevelyan, 2007). The process of reflection in BSE practice is often inspired by discrepancies in existing knowledge, skills and indeed practitioners' attitudes. These disparities described as an *experience of surprise* (Schön, 1983) is analysed constructively and critically, resulting in the development of new perspectives of the situation. BSE management, like other professionals, exercise competency when challenges are imposed.

By adapting a reflective practitioner role, management develop the necessary skills to confidently and successfully handle practice problems. A reflective manager not only thinks rationally and cognitively, but also embodies *in-action* and for whom critical reflection is valued (Adams, Turns, & Atman, 2003).

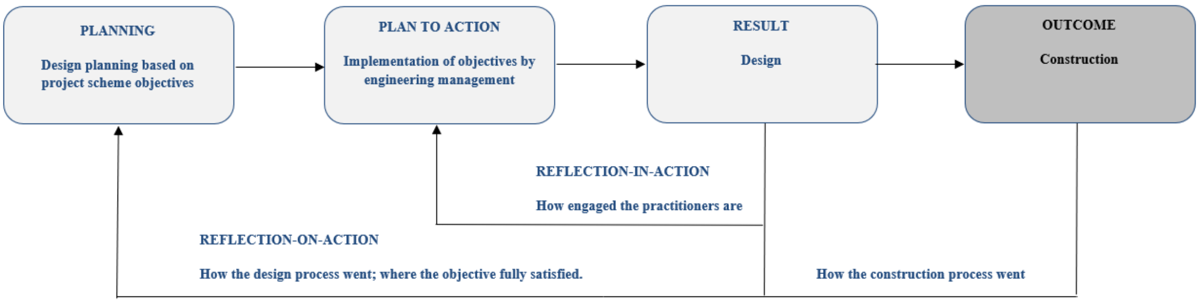

Figure 11 *Schön's reflection model adaptation* **(Reilly, 2014)**

Thus, the reflective manager interactively frames the problem, and generates *moves* towards a solution and reflects on the outcomes of these moves. In this process, management functions as both a *creator*, developing a solution, and an *experimenter*, understanding the situation they are creating, hence the notion of having a *reflective conversation* with the situation (Schön, 1983).

Critical reflection engages management in a process to draw upon critical perspectives, linking their learning and work experiences, to understand and change interpersonal and practice (Rigg & Trehan, 2008), which has gained legitimacy, particularly in terms of practice and professional development. Being involved in the process of critical reflection, management is in a position to interpret and create new knowledge, and new behaviours (Rigg & Trehan, 2008). This leads to new conceptual perspective and understanding, whilst captivating the process of continuous learning (McClure, 2014).

Management is challenging with different tasks and different approaches to practice problems. The adoption of a divergent *(feel and watch)* reflective approach in practice can be affected by various factors, such as the knowledge, skills, perspectives, previous trainings, and experiences; working environments; available resources; and interactions with clients (Choi & Hong, 2009). These reflective dialogues assist management to make sense of new information and feedback within the context of their own experience (Hinett, 2002).

Gibb's reflective cycle also provides a basis to guide reflective practice *(Figure 12)*. However, rather than describe a unique situation, it focuses on the effect the experience had on management, thus their subsequent learning that occurred and their future learning (Jasper, 2003).

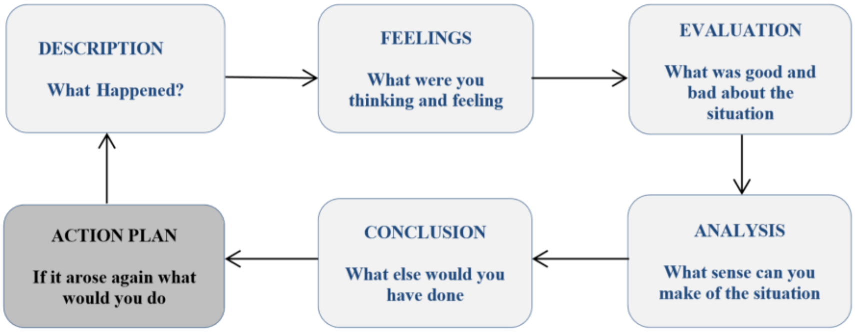

Figure 12 *Gibb's reflective cycle* (Bolton & Delderfield, 2018)

For relevance to this inquiry, the researcher has developed an integrated model of reflective practice *(Figure 13)*, which accounts for the dynamic, cyclic, and unfolding nature of BSE management. This model incorporates Kolb's reflective practice, experiental learning cycle and learning styles and knowledge conversion, and serves to underpin the consequential interplay between *change* and *learning* in practice.

The four key stages in reflective practice are identified as *(i)* concrete experience, *(ii)* reflecting on it, *(iii)* theorising what shaped the experience, and *(iv)* active experimenting on such theories (Kolb, 1976). The four stages of experiential learning are recognised as *(i)* the phenomena, *(ii)* analysing the relevant data, *(iii)* conceptualising what shaped the experience, and *(iv)* applying what was learned from the experience. In this learning situation, management begin by deciding whether they want to *feel*, *watch*, *think* or *do* (Kolb, 1981). The researcher synthesied a combination of all four learning styles to reflect this inquiry, that is, the *diverger*, the *assimilator*, the *coverger* and the *accommodator (Figure 13)*.

The *diverger* is imaginative and sees things from different perspectives. Their greatest strengths lie in the ability to view concrete situations from many perspectives in a creative and imaginative manner, which infers that BSE management belongs to this learning style. The *assimilator* is capable of creating theoretical models by means of inductive reasoning and synthesising various ideas and observations into an integrated whole. For this learning style, management is more concerned with sound logical theory, which alludes to the researching professional.

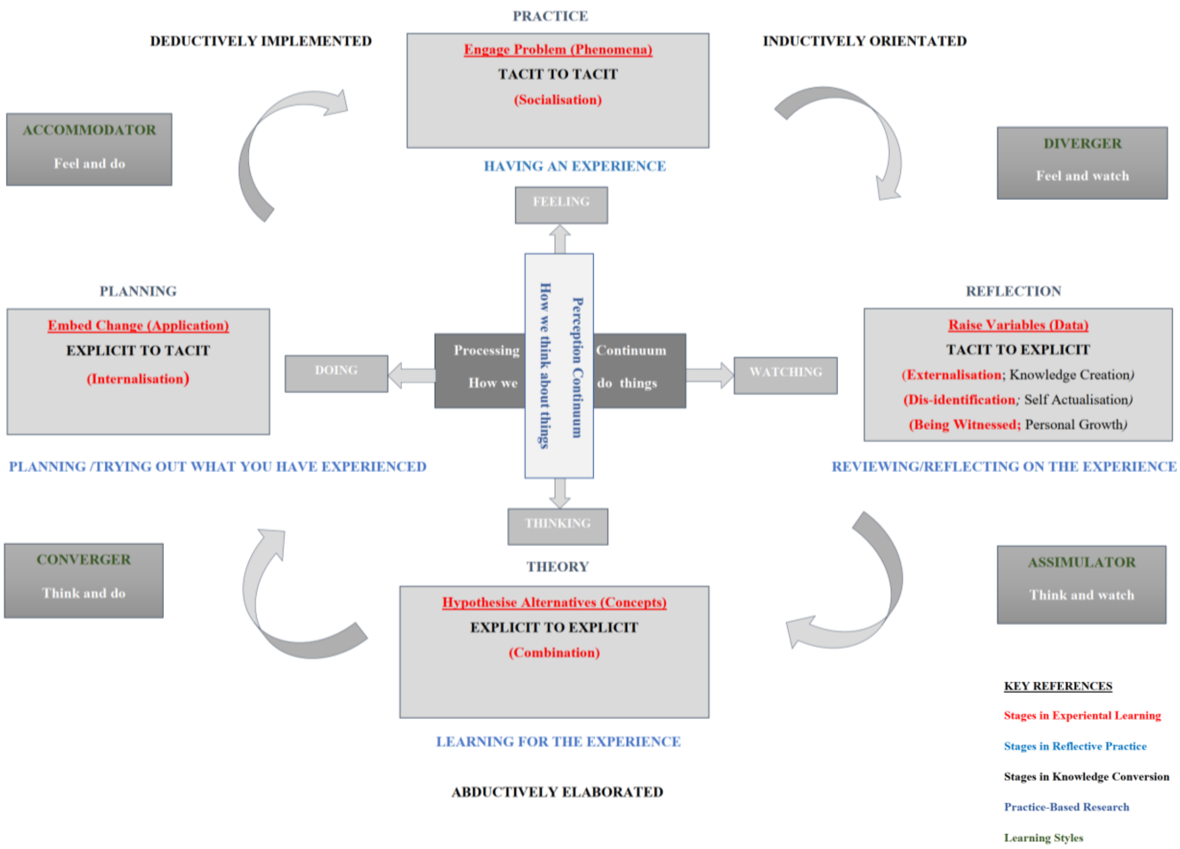

Figure 13 *Theory of reflection in BSE Practice* (Bolton & Delderfield, 2018) (Mann, 2013) (Kolb, 1981) (Reilly, 2014)

The *accommodators* are active engagers, doing things instead of merely reading about and studying them. They involve themselves in new experiences. In situations where a theory does not fit the facts, they tend to discard it and try something else. They often solve problems in an intuitive trial-and-error manner, relying heavily on others for management**.** Finally, and perhaps most relevant learning style to this research is the *converger*. The converger makes practical applications ideas and uses deductive reasoning to solve practice problems. Management that advocate that this learning style does best in situations where there is a single correct solution to a problem; this learning style is often adapted in BSE practice.

Learning by experience without reflection is an inaccurate process if mistakes are uncritically repeated (Robertson, 2005). Learning from experience through reflection contributes to the overall mastery in professional practice. Indeed the tendency of practice to continue on the same path is tempting (Morrey, Pasquire, & Dainty, 2010). Research cites that the *failure to learn* is the greatest cause of practice downfalls (Engineers Ireland, 2016).

2.4.1.4 LEARNING IN PRACTICE

The act of learning in professional practice is directly related to how management can stimulate learning (Reilly, 2014). A learning practice is skilled at creating, acquiring, interpreting, transferring and retaining knowledge. A knowledgeable practice works with new ideas, comes up with new scenarios, and implements them throughout the practice. If the rate of learning is not greater than the rate of change in their discipline, the practice will fall behind (Stata, 2014). However, BSE management is now in a position to foster and inspire this learning process.

The key resource in professional practice is related to its core competences, and includes collective learning by coordinating diverse management skills, and integrating multiple streams of processes (Prahalad & G. Hamel, 1990) (Bettis, Bradley, & Hamel, 1992). By implication, the core management competence in BSE practice underpins an efficient design process, which can differentiate a practice from competitors (Parry, Mills, & Turner, 2010). Many BSE practices' core competences degrade over time becoming threshold competences primarily due to the development of competitors' management strategy (McIvor, 2000) *(Figure 14).*This research appraises practice-based experience of the design process to visualise the complex interaction that exists between this design process and competence.

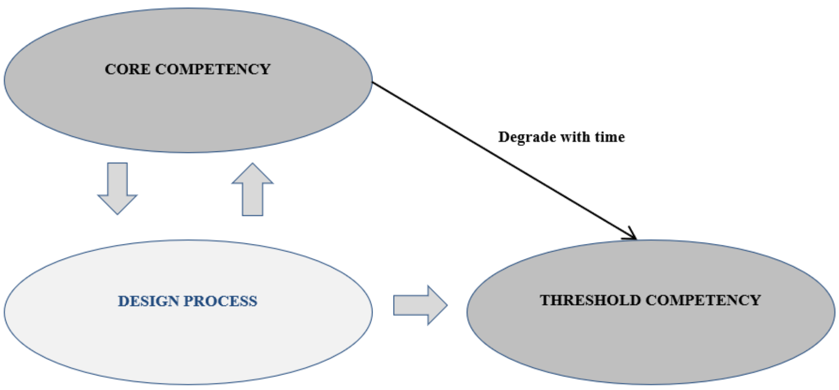

Figure 14 *Interaction between competency and strategy* (Parry, Mills, & Turner, 2010)

Practice learning is more than simply acquiring new knowledge and insights; it requires management to unlearn old practices that have outlived their usefulness, and discard ways of processing experiences that may have worked in the past *(Figure 15).* Adapting new concepts requires management to unlearn and relearn new processes (McGill & Slocum, 1993). The development of practice, and inherently, the scholarly accounting of practice, ensues an awareness of management and their competence (Mann & Clarke, 2007).

Existing theory argues that their openness and commitment or resistance to practice changes shapes their reactions and the degree to which they master learning (Cunningham, Dawes, & Bennett, 2004).

Learn ***Unlearn*** ***Relearn***

Figure 15 *The learning approach* **(Conner, 2015)**

2.4.1.5 MANAGEMENT IN PRACTICE

What is now achieved was once only imagined (Blake, 1827). It is long distinguished that projects are not only successful due to effective management, but occur as the result of understanding their role in fostering an environment for success (Lawlor, et al., 2014). Management matters most in times of uncertainty and change; times when practice craves clarity (Dewan & Myatt, 2007). They have the ability to seek the best counsel, make firm decisions on the path forward, and ensure that their practitioners understand their role in a shared vision (Bamber, 2012). However, management's inherent unwillingness to unlearn traditional orthodox processes often has a negative impact in practice (Niri, Mehrizi, & Atashgah, 2009) (Morris & Pinto, 2007). The evolutionary and disciplinary nature in BSE practice dictates the need for modernisation to address any shortcomings of the traditional approach (Farmer, 2016) (Roper & Pettit, 2002) .

The thinking process of management is one of the most important issues in managerial research. Based on theoretical assumptions, thinking in engineering practice is reduced to the four basic cognitive operations of *exploration*, *generation*, *comparison* and *selection*, which in various combinations are applied to BSE practice. These basic cognitive operations can be mapped onto different stages of the design process (Stempfle & Badke-Schaub, 2002) by five comparable steps to the project *content*: (i) *planning* (ii) *analysis* (iii) *evaluation* and (iv) *decision*, and (v) *control (Figure 16).*

This model implies that the decomposition of complex processes into small portions can be analysed by a variety of methods to form a precise picture of engineering practice (Stempfle & Badke-Schaub, 2002). However, it is also intimated that these processes do not wholly deliver projects; practice management does (McKinsey Capital Projects, 2018) (Ehrlenspiel, 1999). Practice management must have the gravitas and credibility to influence industry peers to convincingly inspire and communicate *why* to promote and instigate change in practice.

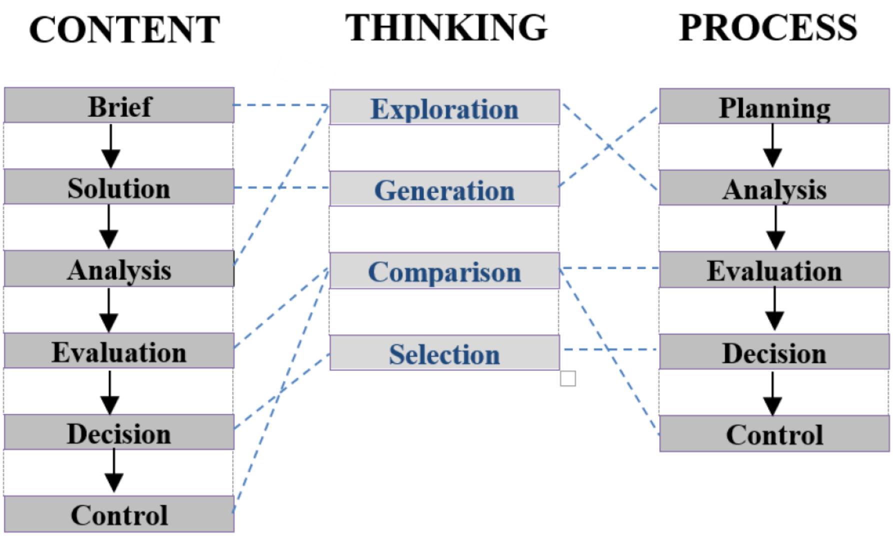

Figure 16 *Management of design process activities* (Stempfle & Badke-Schaub, 2002)

The performance of Irish projects has been historically poor and prone to overruns despite extensive research, literature and practice. Many root causes are related to the management of processes and technical mastery. A critical element for successful project delivery is *soft* issues, such as practice management, practice culture and team attitudes (McKinsey Capital Projects, 2018). Creating and maintaining softer elements over a period is an art required to manage and deliver on project challenges.

An effective manager has a unique and shared identity to create a culture of mutual trust and collaboration, where management articulates purpose, role model behaviours, and nourishes the desired culture. Strong and transparent trust-based relationships with stakeholders is imperative to enable prevention and rapid resolution of problems. Enhancing current practice with a focus on soft practice and management elements of project delivery presents the mastery that increases the probability of a successful practice *(Figure 17).*

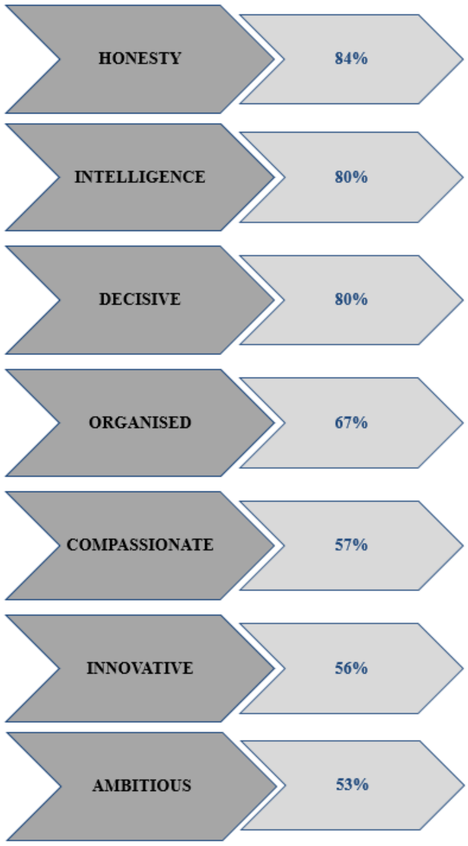

Figure 17 *Management traits (Pew Research Laboratory, 2014)*

Practitioner skills under-represent the importance of practice management; young practitioners are educated at higher education institutes in the science of project management, and their formative years in a practice environment are spent mastering the systems, processes, and methodologies of specific disciplines. This art is generally learnt more informally, through experience, and often finds its roots in the wisdom learned from mistakes, which is usually implicit (McKinsey Capital Projects, 2018). Practitioners consistently reinforce the importance of management as a vital and necessary complement to practice.

2.4.1.8 PRACTITIONERS

Engineering is increasingly being recognised as a technical and a social discipline, both inextricably intertwined (Bucciarelli, 1996). There is limited literature available to examine this interaction in engineering practice (Trevelyan, 2009), and therefore, the social aspects can easily be taken for granted (Bucciarelli, 1996). It is argued that engineering practice cannot be separated from the *people* context in which it operates, and needs to be understood as a much broader human social process than traditional narratives that focus just on design and technical problem-solving (Badawy, 1995).

Social interactions lie at the core of engineering practice, whereby a full appreciation can only be valued when it is understood how people think, feel, act and interact as they perform. Thinking is human, and there is a need to recognise that even technical accomplishment is limited by human capabilities (Trevelyan, 2010). By implication, the design process relies on management to harness knowledge, expertise and skills. Inherent explicit and tacit knowledge is habitually developed through years of practice, but can be difficult to transfer to practitioners. (Ericsson, 2003). This transfer gap infers dissonance between management and practitioners, and hence, the need to improve the technical-social dualism (Faulkner, 2007). Moreover, it is implied that 85% of financial success in engineering practice is due to soft management skills, whilst only 15% is due to technical knowledge (Carnegie-Mellon-University, 2016). However, there is frequently an unwillingness by management to unlearn traditional management techniques (Niri, Mehrizi, & Atashgah, 2009).

2.4.2 PROCESSES

BSE management conceptualise the design process as a progression of transforming inputs into outputs, a flow of information through time and space, and a course for generating value for clients, which if correctly represented, can be repeated from one project to the next that can be defined, measured and improved upon. The literature alludes that management is deficient in both transforming inputs into outputs, and providing an efficient flow of information through design and construction stages (Akbıyıklı & Eaton, 2011). It is argued that only when based on suitable conceptualisations, and informed by empirical data, can this process be improved to modernise practice (Kostela, Huovila, & Leinonen, 2002).

BSE practice is facing increasing competition in Ireland, and to remain in business, it must continually innovate. Inferior design is becoming more costly to rectify later, which can be particularly damaging if it is not discovered until the design is installed (Hales, 2014). High quality engineering design with sound management is crucial to the financial success of practice. Very often in practice, management believe they know and understand their business process, but in reality, many do not really understand it well enough to judge if it can be transformed (University of Salford, 2014).

Remarkably, it is recognised that 75% of the problems encountered at construction stage are generated at the design stage (Mendelsohn, 1997), but their impact is rarely understood in terms practice dysfunction. Moreover, it is estimated that an additional 40-50% of the total work hours of a project may be required by design practices to rectify such deficiencies at construction stage (Kostela, Huovila, & Leinonen, 2002).

2.4.2.1 DESIGN MANAGEMENT

Effective management practice must be embraced and continuously addressed throughout the design process. Developing a responsibility matrix from the outset strategically defines the role of each practitioner, which identifies networks between tasks and disciplines. Despite the apparent straight forward nature of its contents, gaining practitioners agreement can be challenging (Portman, 2014). Overlapping of responsibilities is common, where one discipline makes an assumption that the other discipline is undertaking an area of work. Management must keep abreast of *soft* and *hard* literature related to their field by continuously reviewing information provided by professional institutes, local authorities and statutory bodies and even trade press (Tymkow, Tassou, Kolokotroni, & Jouhara, 2013) (Engineers Ireland, 2013).

2.4.2.2 DESIGN PLANNING

An effective and workable design plan is essential to exert managerial control over the design process to improve coordination between engineering disciplines (Austin, Baldwin, & Newton, 1994). Poor understanding of discipline interdependency of information flow during a project lifecycle is normally a result of disciplines not understanding how their work contributes to the project whole, causing a fragmented approach to planning (Phelps, 2012). This creates implications for the technical coordination of design and general process control (Newton & Hedges, 1996). Another facet of poor design planning is that resource allocation is often unbalanced (Cornick, 1991). This can cause initial delays, but can also escalate into communication problems amongst the project team (Kostela, Huovila, & Leinonen, 2002).

It is imperative that BSE practice is appointed to a project design team in a coordinated manner, as any uncertainties in conditions of contract will create commercial pressures, and may be detriment at design and construction stages.

This can be exacerbated where the appointment leaves gaps or create overlaps in design activities, and particularly in the provision of design information (Government Construction Contracts Committee, 2009). This scenario becomes a serious risk for all concerned, including the client. Ambiguity over design activities leads to project delays, increased contractual claims, and litigation. Even where integrated teams are appointed, care must be taken to avoid gaps and duplication in design activities.

BSE design process starts with the initial recognition of the client needs and ends with the operation of a completed building (Portman, 2014). Traditionally, architectural concepts are normally thought-out initially, with BSE input following suit. Today BSE design should be front-loaded to collaborate early with other disciplines in the preliminary design criteria development process. Through digitialisation, BSE practice is now is a position to adopt modern decision-making tools, prediction models, processes, procedures to prescribe how the design process is managed; a process in which engineering practice can apply resources optimally to meet project objective (Management Solutions, 2014).

Interestingly, the Building Services Research and Information Institute (BSRIA) offers the UK AEC industry an excellent design framework guide in BSE practice, which reflects the intent to overcome project coordination problems, and presents the means by which design activities can be clearly and openly allocated amongst the team throughout the project lifecycle (BSRIA, 2018). This framework aligns with the new 8-stage RIBA plan-of-work in UK contracts, which has been recently amended to take cognisance of sustainability, BIM and procurement *(Figure 18)*. On the contrary, it can often instigate problems of alignment in Irish BSE practice where a 5-stage plan-of-work is applicable in both the public and private sector contracts *(Figure 19)*. The practice-based case study project presented in this research was procured under a public sector contract.

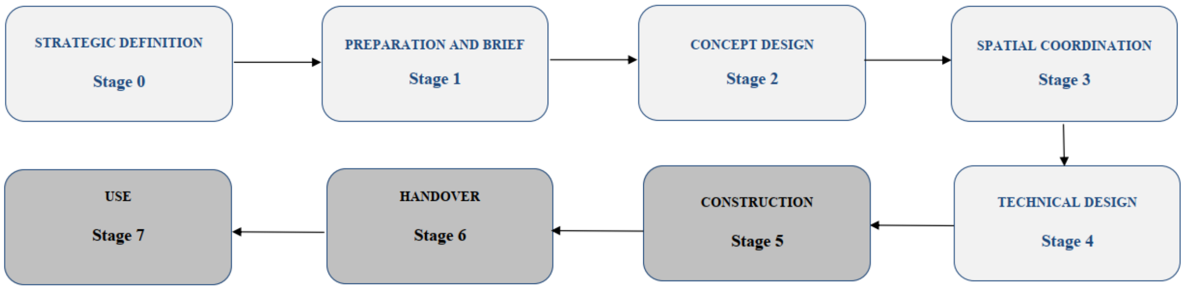

Figure 18 *8-Stage plan of work 2020 (RIBA, 2019)*

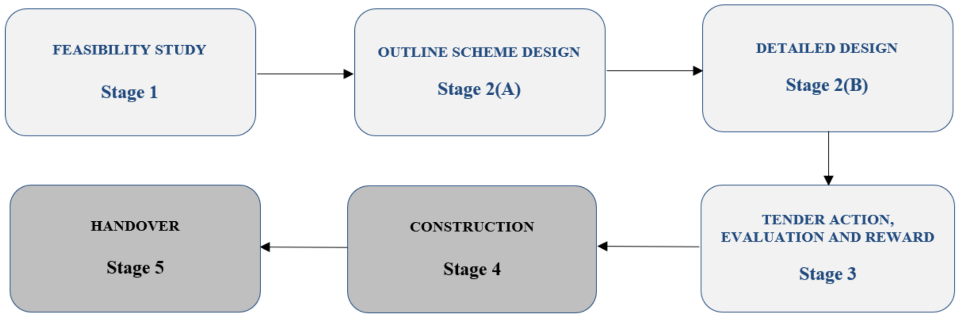

Figure 19 *5-Stage plan of work (Office of Government Procurement, 2019)*

Undoubtedly, RIBA Sustainable Futures Group, which has developed a series of sustainability guides to support the RIBA Plan of Work 2020 is of great guidance to the Irish AEC industry. The overriding aim to distil and simplify the existing and varied sustainability guidance to set measurable sustainable outcomes and targets aligned with the United Nations sustainability development goals (RIBA, 2019) act as a reality-checked throughout the design and construction stages, and verified in post occupancy evaluation. In addition, the plan-for-use produced by BSRIA aims to encourage a more *in-use* approach to design, which translates into a positive change within practice, discipline and profession.

This sustainability strategy maps the sustainable outcomes and *plan for use* principles through all stages of the plan-of-work, which reinforces the requirement to appoint a sustainability champion in BSE practice, thus creating a context focused sustainability strategy at the project outset (RIBA, 2019).

2.4.2.3 PROGRAMME, TIME AND VALUE MANAGEMENT

BSE management varies greatly in how they control their projects. Their performance varies from smooth easy productivity to complete chaos ending in failure (Bender, 2013). Developing and managing a project delivery programme can be a daunting task for management, but well worthwhile, if considered in a strategic manner. Ensuring that activities are complete to achieve project objectives by articulating tasks, allocating resources and durations for the individual tasks, and identifying the interactions between the different tasks, and plotting their execution against predetermined milestones in the context of cost or time is paramount to the successful delivery of any project (Venkataraman & Pinto, 2008). This procedure facilitates succinct monitoring to control progression during the design process.

The most influential factor to a successful design process is the ability to manage time. Interruptions or other demands that impede *real engineering* work are the enemy (Trevelyan, 2014). Notwithstanding the literature, where interactive activities are critical for the completion of their tasks, management often describe administrative activities as a disruption in practice. This can lead practice into a vicious work-time cycle of time pressure to complete design leading to a crisis mentality, which can result in individual heroic behavior causing constant interruptions to others/ *Firefighting* is the term often used to describe this phenomenon (Bohn, 2000). Management need to respond to this shortcoming effectually. The more time freed up from doing wasteful jobs in engineering practice, the more time that can be allocated to adding value to design process (Enterprise Ireland, 2014).

2.4.2.4 RISK MANAGEMENT

Risk is unavoidable and present at design and construction stages, and concerns the uncertainty that surrounds future events and outcomes. It is the expression of the likelihood and impact of an event with the potential to influence the achievement of objectives by practice. Risk management integrates recognition of risk, risk assessment, developing strategies to manage it, and mitigation of risk to an acceptable level by management (Portman, 2014) (Berg, 2010). If risks are realised by loss or damage, depending upon the particular circumstances, measures may be sought by the injured party from the party responsible.

BSE management is responsible for assessing the project risks during and after-design, assessing the potential impact and taking the steps necessary to mitigate those risks, which can have as large an impact on cost and programme schedule. Managing risk is a key process, and involves gaining management’s commitment to assist in controlling the technical and business risks in practice. Effective risk management encompasses elements of timing, managing the political environment in the practice, and being sensitive to the needs of the greater project team (Armstrong, 2001).

Hazard elimination and risk management are iterative processes, and therefore, changing or developing design requires resultant hazards to be reduced or mitigated. The key element in effective risk management and compliant design is to undertake hazard elimination and risk reduction as an up-front integrated part of the design process.

Independent design peer review meetings are often a useful means for this purpose, whilst also contributing to the effective sharing of BSE specialist knowledge and experience on projects (Tudor, 2018).

Safety in design is imperative; decisions made by management affect the health and safety of system installers, building occupants and maintenance. Therefore, managers play an important role to ensure that their practitioners' design do not create compliance difficulties. Managing risk can positively affect a project (Tudor, 2018). Early decisions during the design process can influence later design options that may be difficult to reverse. Management is in a unique position to disseminate practitioner skills, knowledge, experience and practice capacity necessary to fulfil their role in a manner that secures the health and safety of people affected by the project. They must be wholly cognisant of significant risks that building occupants can also be exposed to, and how these can arise from design decisions, thus effectively coordinating design with other design disciplines to improve the manner in which risks are managed. Decisions taken by management during the design process fundamentally influence the risks faced by installers and occupants of the building (Portman, 2014). Health and safety is an integral part of the BSE design process, and must not be deemed as an afterthought (Nahmens & Ikuma, 2009).

2.4.2.5 QUALITY AND PERFORMANCE MANAGEMENT

Quality management during the design process is imperative to prevent quality problems by systematic planning of activities, and defining a quality policy with intentions, aims and directions, and monitoring it by a quality control regime (Carmona & Sieh, 2004). A thoroughly developed strategy will improve the feedback cycle, thus creating a practice self-improving quality regime to increase efficiency and eliminate unnecessary costs from errors and mistakes. Despite the fact that the process is administrative, substantial improvements in meeting quality requirements can be achieved (Burati, Matthews, & Kalidindi, 1991). It is common in BSE practice to review deliverables amongst peers at the end of the design process to assess the integrity of design documentation, compliance with statutory and legislative standards and codes, and improve the overall design quality (Portman, 2014) (Savanović & Zeiler, 2016).

More recently, the use of Virtual Reality (VR) and Augmented Reality (AR) technologies further enhance the digital design review process by immersing stakeholders in full-scale simulations and visualisation of the design. These digital constructs facilitate early identification of problems during design development to curtail risk at construction stage (Behzadi, 2016). The inclusion of visualisation and immersive technology is transforming the design process by blurring the lines between the physical and digital world (Fossett, 2016).

Adapting an active quality management procedure creates an environment supportive of gauging performance, and its role in sustaining a competitive advantage in practice (Flynn, Schroeder, & Sakakibara, 1995). Moreover, effective performance measurement and management can provide a means of improving the design process by distinguishing between perception and fact at three levels; *individual*, *project* and *organisational* (Torbett, Salter, Gann, & Hobday, 2001) (Portman, 2014). This measurement and analysis of performance indicators are intended to assist management in making more effective decisions, which are difficult to measure in real practice (Bibby, 2004). The iterative and sometimes poorly defined nature of the BSE design process, the lack of information flow and a number of subjective influences make it challenging to ascertain the benefits resulting from improved performance (Khandani, 2005). The primary reasons for undertaking performance measurements embrace quantifying both the efficiency and effectiveness of actions (Behn, 2003), improving the design process performance, indicating the status and direction of a project, and providing a basis for selection of resources.

Despite its significance, there is no universally accepted structure for assessing project success. Traditionally, the focus has been on three success criteria of *cost*, *time* and *quality*, which focus on short-term aspects of performance (Chan, 2001). Measuring and valuing the quality of design has become a key issue in engineering design practice to improve practice performance (Lia, Nathanb, & Subb, 2004). However, BSE practice is about speculation and innovation with ingenuity in problem-solving. An important question for design performance measurement is whether improvements in design alone can lead to step changes in performance (Torbett, Salter, Gann, & Hobday, 2001). A change in the design process can only be effective if management is tied to an optimisation production process, that is, the improvement in design needs to be part of wider performance improvement programme to be most effective (Roper & Pettit, 2002).

Typically, if there is a mismatch between performance measures and real practice, management will object to what they see as time-wasting number crunching exercises (Torbett, Salter, Gann, & Hobday, 2001). Design performance measurement works best when management is involved in the data collection and interpretation, as opposed to key performance indicators that focus on benchmarking projects retrospectively, which are of little use for controlling the design process, as they do not provide the opportunity for change (Behn, 2003) *(Figure 20).*

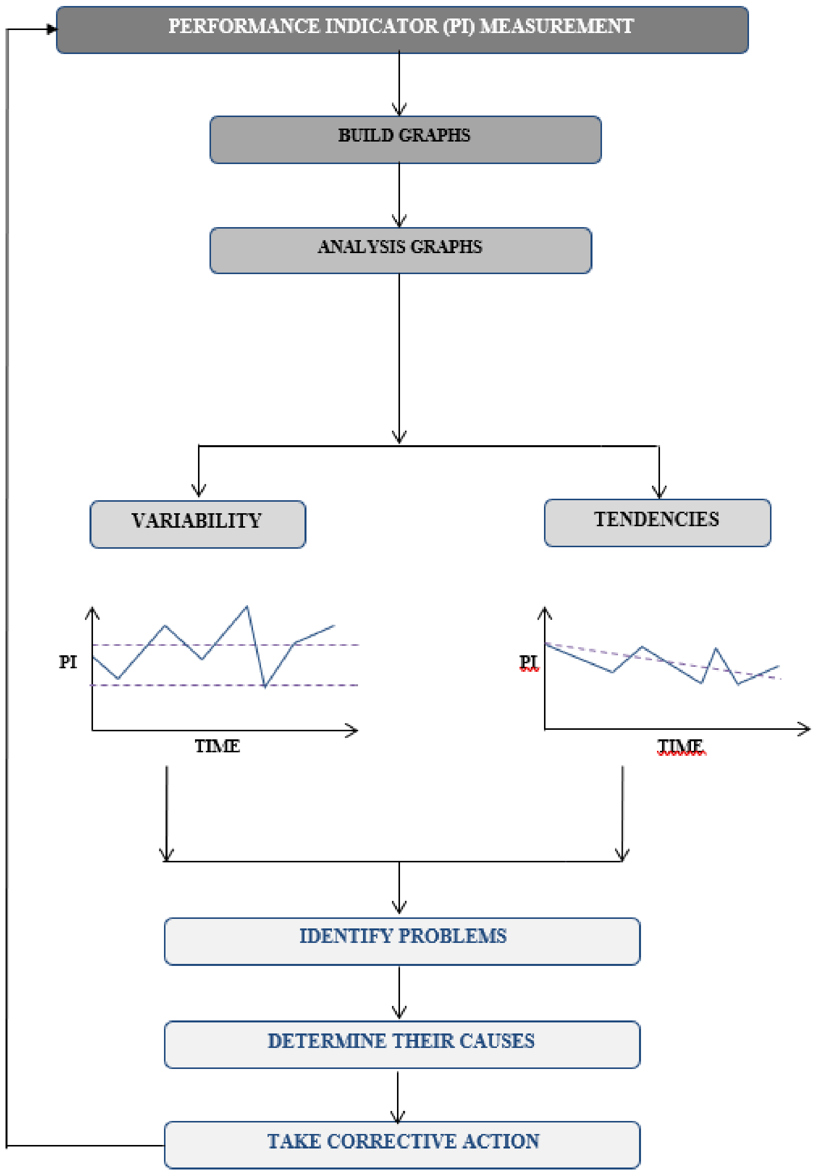

Figure 20 *How performance indicators support management actions* (Portman, 2014)

2.4.2.6 TECHNICAL COORDINATION

Design is an activity shared between several design disciplines that do not always share the same knowledge and often have contradicting objectives designing a project, which often generates problems of coordination (Prudhomme, Boujut, & Brissaud, 2003). BSE practice comprise of multidisciplinary designers who possess individual skills and knowledge, but with one common untaught skill necessary; *technical coordination*. The proficient management of this process comes with experience and working with practitioners from different disciplines.

The key problem facing Irish BSE practice is technical coordination that requires an multidisciplinary approach to integrate diverse perspectives into a collective whole. Matters of direction and control in practice demands competent management to ensure profitability and the provision of a value-for-money service to the client (Dave, Koskela, Kiviniemi, & Owen, 2013). Management needs to understand holistic design to gain its full value (Trevelyan, 2010). An empirical survey provides evidence that coordinating technical work of practitioners is primarily achieved by gaining their willing cooperation; a major aspect of engineering practice (Trevelyan, 2007). Whilst coordination would appear to be non-technical, foregone research provides evidence supporting the critical importance of this technical expertise.

Coordination normally involves one-on-one relationships with management, practitioners, clients, and stakeholders (Trevelyan, 2007). The literature also suggests that management is completely separate from engineering; a practitioner is either a manager or an engineer; the former supposing little or no technical content in their work and the latter having little or no social dimension to their work (Barley & Orr, 1997). However, the prominence of coordination strongly suggests that BSE management relies on a social process at the microscopic level of individual interactions between practitioners (Trevelyan, 2007). The value that arises from the contributions of practitioners is created only through the actions of management and the wider project team, often far removed from the setting in which practitioners perform their work (Sonnentag, Cornelia , & Volmer, 2006).

2.4.2.7 INFORMATION AND KNOWLEDGE MANAGEMENT

Information management ensures that the right data is available when required in the right format. This involves implementing the necessary tools and practices for the collection and management of information from one or multiple sources and the distribution of information to the relevant parties (Webb, 2008). BSE practice has recently veered towards cutting edge digital management systems, which store, share and manage design documentation. This common data environment enables project data to be accessed by other disciplines at all times for the latest information (Portman, 2014) *(Figure 21)*.

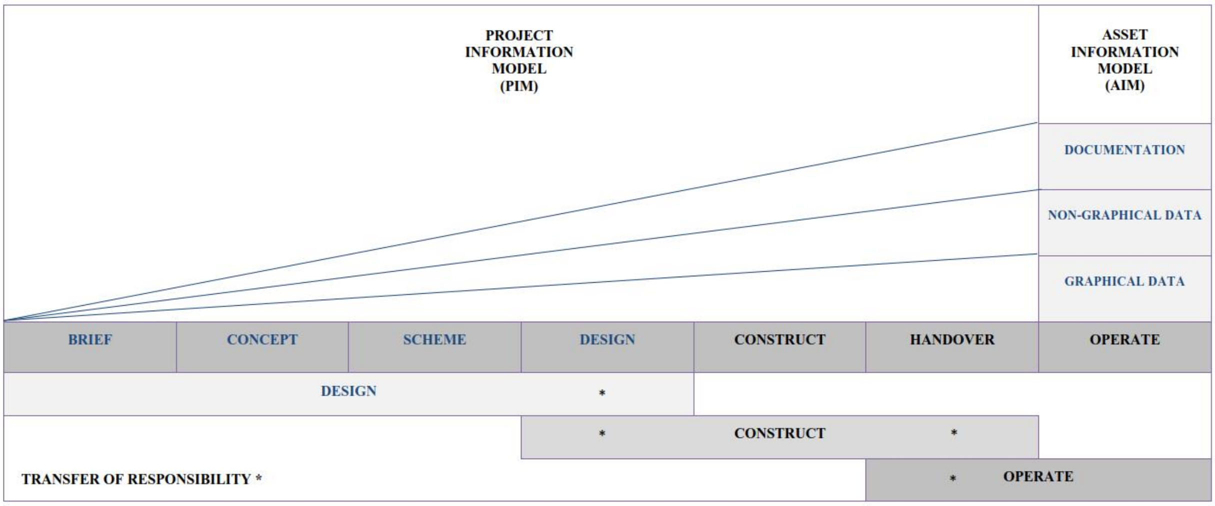

Figure 21 *Common data environment*

From a practice concerted perspective, the inherent design process is iterative in many respects, where management tend to adapt a *not reinventing the wheel* approach to design by reverting to previous design strategies (Dalkir, 2005). This is not a new concept as practitioners have been concerned about improving the re-utilisation of knowledge for centuries, where a distinct field called *knowledge management* has emerged (King, 2009). The contribution of information management to the knowledge management process is imperative, where practice strives for innovation to gain a competitive edge (Nawab, Nazir, Zahid, & Fawad, 2015). Modern information management systems have the capacity to integrate *people*, *processes* and *technology* throughout the project lifecycle, which allow the secure sharing and storage of information enabling numerous disciplines to collaborate effectively, provide project visibility, and mitigate risk.

Management often spend their time controlling information during the design process, which is often incorrect with little or no real value, without full consideration on the negative effect or impact, or even the purpose of the information produced. The fragmented structure in BSE practice, and the disjointed and adversarial manner in which design is produced, management often have no choice but to work in a vacuum of limited scope without an understanding of the whole project objectives.

Surprisingly, it is common in practice for design information to be completely reproduced, or extensively edited and changed during design or construction stages, and still not be correct, but available on time to execute construction without rework, abortive work, delays, variations, claims, and disputes. Paradoxically, management is fully aware that it is incorrect, but to meet arbitrary deadlines and deliverables, they continue managing the production of incorrect, insufficient, or unnecessary information.

2.4.3 TECHNOLOGY

2.4.3.1 DIGITAL CONSTRUCT

The key resource in engineering practice relates to its core competences (Bettis, Bradley, & Hamel, 1992), including the integration of multiple technology streams (Prahalad & G. Hamel, 1990). The literature infers that failure to embrace new technologies in practice can lead to professional obsolescence (Engineers Ireland, 2016). Therefore, it is the responsibility of management to administer appropriate technologies taking cognisance of their cost to procure, time to implement, and indeed their accuracy (Sheppard, Colby, Macatangay, & Sullivan, 2006).

In an effort to remedy stagnant labour productivity in the late 1980s in Ireland, Building Information Modelling (BIM) was anticipated as a new solution for streamlining the design and delivery process of construction projects, which preceded constructive solid geometry (CSG) and boundary representation (BRep) technologies (Monchaux, 2011). Despite the huge potential to increase productivity and overall efficiency, BIM adoption throughout has been observed slower than expected (Walaseka & Barszczb, 2017). However, the inherent lack of integration often coupled with poor collaboration leading to over-budget and programme implications delivered by the traditional 2-D design delivery system proves to be an insufficient method at design and construction stages.

BIM is now perceived as a paradigm shift to the next-generation solution for streamlining the project delivery process. However, with the AEC industry showing signs of fragmentation, barriers are expected when adopting new digital processes (Porwal & Hewage, 2013). BIM is about moving away from traditional industry practice to facilitate better communication and sharing of information, thus creating a building model that represents its physical characteristics, its performance, the way it will be built and flexing its benefits to the project team involved in designing, constructing and operating it. It is about using technology to improve the workflows, communication and processes in an industry that is traditionally very fragmented (Bhatt, Borrmann, Amor, & Beetz, 2013) (Jung & Joo, 2011). In current practice, great disparity exists in the level of effort placed on the technical coordination process, and the timing in which coordination is performed. Multidisciplinary design often conflicts, and thereby, contributing to the source of installation disruptions. Whilst it is understood that technical coordination efforts can reduce disruptions by minimising field conflicts, limited data is available to demonstrate the value of coordination in real terms (Riley & Horman, 2012).

A BIM initiative presents an opportunity to improve the design process, thus elevating the importance of removing avoidable risks during the construction stage (Dave, Koskela, Kiviniemi, & Owen, 2013). Recent technological development in prediction software also offers an integrated BIM 3-D design (Szeląg, Szewczak, & Brzyski, 2017), which is demonstrating to be a game-changer in BSE practice. In particular, MagiCAD was developed as a powerful design tool to save time during the design process with more user-friendly, flexible, intelligent, and parametrical user environment (MagiCAD, 2016) *(Image 1).* Its implementation in practice is at an early stage, where its practicality and effectiveness is also difficult to justify at this stage (Szeląg, Szewczak, & Brzyski, 2017). This digital design strategy was successfully implemented at the practice-based case study project *(Images 2, 3 & 4).*

Image 1 *Synchronized BSE BIM model applying MagiCAD* (Admea, 2015)

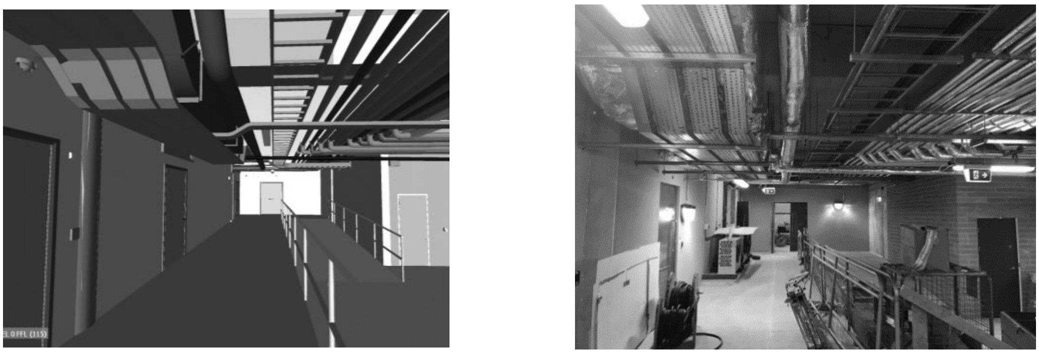

Image 2 *Practice-based case study - Main mechanical and electrical services routes*

Image 3 *Practice-based case study – Grandstand great hall*

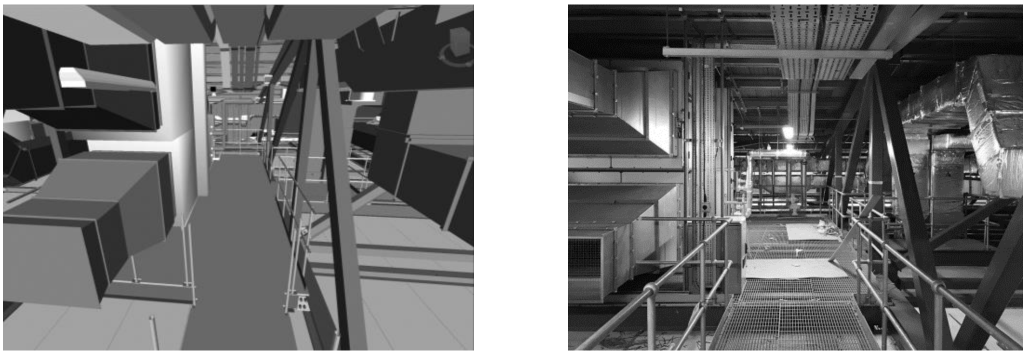

Image 4 *Practice-based case study – Main plant room*

2.4.3.2 DIGITAL SMART

BIM has the potential to bring significant change to the AEC industry, yet its adoption rate varies hugely across Ireland. Whilst larger BSE practices use BIM on every project, smaller practices are more wary of this new way of working despite its capacity to generate a digital representation that integrates data from multidisciplinary sources to create, manage and share information over the entire project life-cycle, thus improving efficiency and communication amongst all stakeholders (Construction Industry Federation, 2018).

BIM adoption is represented at four levels taking cognisance of maturity and ability to exchange information digitally within the supply chain *(Figure 19).* Level-0 projects use 2-D CAD with little to no digital collaboration, whilst Level-1 projects introduces digital elements with a mix of 2-D and 3-D drafting. A common data environment (CDE) is deployed to share data electronically within the project team. Level-2 projects are data-rich, where cost, scheduling information is linked and managed in a 3-D environment.

The project team can combine their data and collaborate through this CDE. Furthermore, Level-3 projects are fully collaborative with a single project view for data integration, whereby all parties can access and modify data subject to processes and security restrictions. Digital data is undoubtedly more manageable than figures on paper, particularly when multiple disciplines are working simultaneously at design stage. A standard digital format, which is universally understood has the potential to generate efficiency savings of 20-25% (McKinsey & Company, 2020).

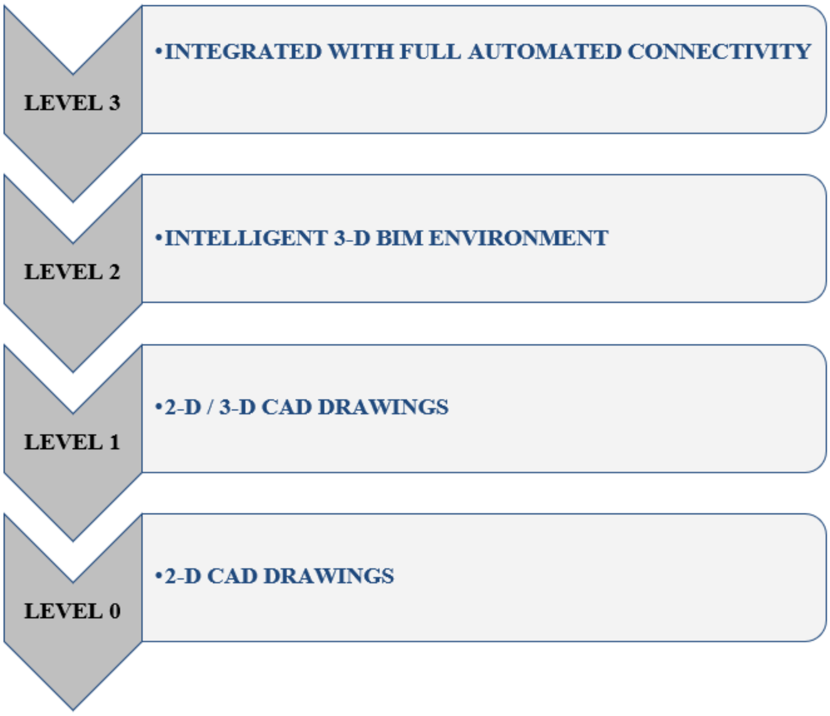

Figure *22 BIM maturity levels* (MagiCAD, 2020)

By defining the Employer's Information Requirements at design stage gives focus to the project team throughout the project. In the event of implementing change, a responsive BIM updates graphical information in real-time, which allow collaborators to receive updated data immediately.

More clients expect AEC practices to implement the BIM process, where open 3-D modelling and the nature of collaboration are appealing, and where accuracy, minimum waste and precise requirements are adhered. BIM could change the Irish AEC industry, which could influence the whole value chain in due course. However, a significant change in mind-set by sceptical practices is required to make BIM work (Deeney, Hore, & McAuley, 2013).

2.4.3.2.1 SUSTAINABILITY

BIM can be used to support sustainability trends. Its adoption is a key part of digitalisation of the AEC industry, and an enabling tool for a cleaner and more sustainable built environment. Management that actively adopt BIM can contribute positively to the BSE design process to make the AEC industry more focused to effectively achieve sustainability and energy efficiency goals and targets (United Nations Environment Programme, 2019). More recently, there is a greater requirement for energy efficiency competencies and applicable skills in Irish BSE practice, resulting from regulated decarbonisation and sustainable energy long-term strategies. As a sustainable energy supportive technology, BIM is a vital tool for reducing the carbon footprint in the AEC industry (Engineers Ireland, 2022).

BIM is the backbone of a new *informed* way of working, triggered and targeted by digitisation and equipped to manage the full energy content of project delivery. Such is the impact of BIM that the Irish government is supporting, promoting, and developing policies and initiatives aiming to foster digitalisation in the Irish AEC industry (BIM Ireland, 2019). However, digitisation and the use of BIM are in their infancy. By harnessing their capacity, many countries can cut emission rates cost-effectively and achieve energy savings of more than 30% (United Nations Environment Programme, 2019). Thus far, this digital journey utilising BIM is generating applications and breakthrough in knowledge, use, and results achieved through the deployment of sustainable energy skills.

The segments within the energy life-cycle for buildings encapsulate *potential, embedded, operational, and sustainable energy (Figure 23),* thereby accounting for all energy used in the overall construction lifecycle. They are mutually dependent, and therefore, should not be considered separately during the design process. Design decisions and actions are not mutually exclusive; decisions made in one segment can impact the entire energy circle.

By association, BIM-based energy modelling provides several benefits, including more accurate and complete energy performance analysis in the design process, improved lifecycle cost analysis, with greater opportunities for monitoring actual building performance during the operation stage.

Nevertheless, BIM is simply an enabler in a digital environment; only practice management can make and implement change - *a tool is only as good as its operator*. The importance of digitalisation and the role of BIM as the new modus operandi of the Irish AEC industry requires upskilling management to embrace in this new reality. Facilitating practice upskill and qualification in addition to the current offering and beyond the traditional academic offering is challenging as it may not always be a suitable pathway for existing practice (Boston Consulting Group, 2018).

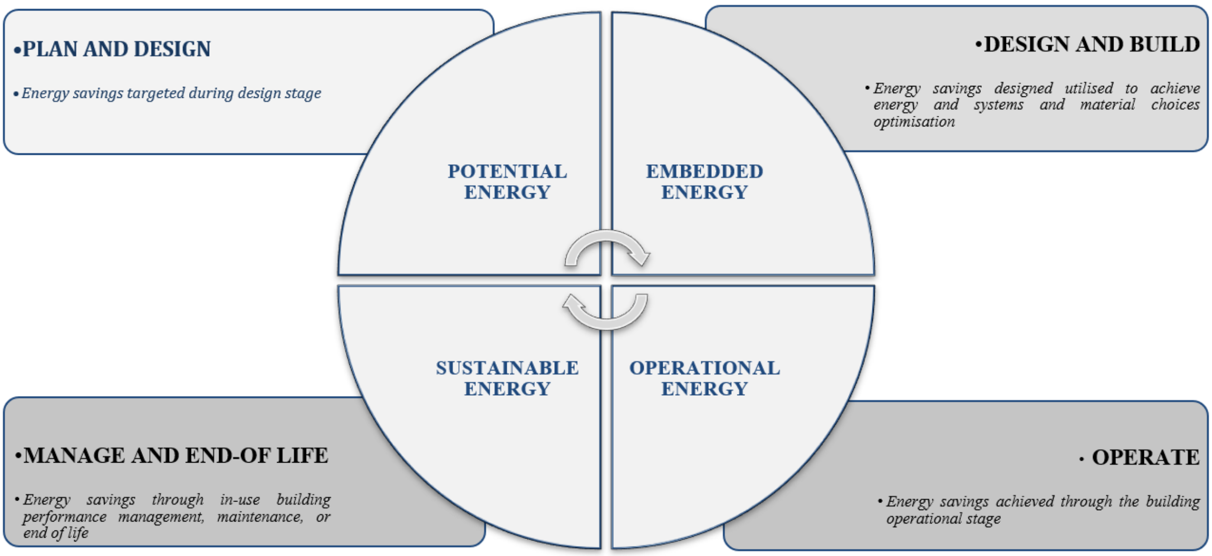

Figure 23 *Energy lifecycle in construction projects (United Nations Environment Programme, 2019)*

2.4.3.2.2 BIM ADOPTION

The implementation of BIM in the AEC industry has accelerated quickly in recent years, and both public and private sector sectors are increasingly recognising the benefits to be gained with this transition to digital technology and the role of digitalisation in creating a more sustainable built environment (MagiCAD, 2020). The private sector has fiscal interests in transitioning to the latest digital technologies, where digitalisation is seen to respond to the combination of declining profitability compared with existing methods.

The overall business impact of BIM is apparent with an estimated value for the European BIM market of €1.8B in 2016, and it is expected to grow to €2.1B by 2023 (McGraw-Hill, 2018). However, the AEC industry has clear financial incentives to make a digital transition. Conversely, the public sector does not have an equal financial burden for digitalisation, whereby BIM is seen as an instigator to reach better social outcomes to the challenges of urbanisation and population growth (ARCOM, 2017).

Nevertheless, as the owner of the public built environment, governmental interest in digitalisation is being driven by many factors, including building quality and efficiency, management of the built environment, sustainability and budgeting (MagiCAD, 2020). BIM implementation responds to a pressure for more efficient public spending, more sustainable development of shared public spaces, and improved management of public buildings.
Additionally, governmental interest in advancing digitalisation supports the welfare of a major industry, which in turn benefits overall economic growth (Royal Institution of Chartered Surveyors, 2020).

The AEC industry plays an important role in bringing together government and business interests in BIM. Projects often include stakeholders from both the public and private sectors, who are well-equipped to represent and facilitate a convergence of interests (Moreno, Olbina, & Issa, 2019). Public sector efforts to encourage BIM implementation are considerably more effective when combined with private sector initiatives, whereby the coordination between the two sectors increases, and the importance as the BIM maturity level in the industry increases. Public sector initiatives and governmental support are imperative at an early stage of BIM adoption, but efficient growth in BIM also commands complementary buy-in and leadership from the private sector (Arbona, 2018). The initial development of BIM implementation has its roots from design practices followed by government initiative at a later stage. As European countries have essentially developed their respective BIM Standards in isolation, its adoption makes coordination challenging at an international level (European Construction Sector Observatory, 2019).

In an information-intensive AEC industry, the adoption of a holistic and standardised BIM approach to information management and the innovative digital ways of working are deemed necessary to achieve a dramatic improvement in delivery and performance efficiencies. This digital technology is creating a positive disruption and constitutes one of the most dynamic ecosystems in Europe in digital transition (BIM World, 2020).

2.4.3.2.3 BIM MATURITY

There is limited evidence and understanding from maturity assessments in the AEC industry for this digital transition. The number of tools and methods to assess BIM maturity, and evaluate its benefits is now more prevalent due to their promised value in guiding BIM implementation, and improving outcomes for practice (Mohamad & Li, 2019). However, the literature implies that BIM evaluation tools have value in promoting BIM to encourage collaborative working, but recommended that these tools be extended to assess benefits throughout the whole supply chain.

None of the maturity assessment tools examined are aligned with ISO 19650, the international standard for managing information over the whole lifecycle of an asset (Chartered Institute of Building, 2019). The literature also identifies positive reasons for measuring BIM maturity to identify BIM implementation barriers and develop improvement strategies. With the lack of benchmarking data and a variation in practitioner knowledge, the task of measuring BIM benefits is complex, whereby it is difficult to eliminate alternative explanations for the relationship between BIM capability and the end benefit (Chevin, 2020).

2.4.3.2.4 BIM AND REVIT

BIM is often mistakenly considered to be a software as Revit. In fact, Revit is one of the BIM tools, which is widely used for the creation of a 3-D BIM model. Comparatively, BIM is a process, where Revit is a tool to leverage that process (Czmocha & Pekalaa, 2014). More succinctly, BIM is a methodology and Revit is a single application designed for inherent building information modeling with features applicable to the three principal design disciplines in the AEC industry; *BSE*, *structural engineering* and *architecture* (Gu & London, 2010).

This multicreation of a digital building information model enables the project team to interact with the building to optimise their actions, resulting in a greater whole-life value for the asset (National Building Specification, 2016). The Revit model thus creates a powerful database containing information at all plan-of-work stages by deploying 3-D intelligent objects with stored information that can provide successful time and cost management during the project lifecycle.

Revit also uses collaborative model building components to analyse and simulate systems and structures, which allow multidisciplinary design practices to work in shared models and import, export and link data with commonly used formats to improve coordination and reduce errors and rework (Autodesk, 2020). In essence, the Revit model enables working with parametric objects, prompt changes with no repetition, automatically produce high quality documentation from the 3-D model, accurate quantities and cost estimation, technical coordination, 3-D visualization, and interoperability, whereby data can be exchanged between design team disciplines (Li, Wang, & Jioa, 2014).

2.4.3.2.5 BIM 360 DESIGN

More recently, and purpose-designed for the AEC industry, BIM 360 design is a cloud work-sharing, design collaboration, and data management product for project delivery, which permits multidisciplinary co-authoring Revit models with greater file and folder-based access controls, and unlimited storage *(Figure 24).* More importantly, this digital tool tracks and delivers technical coordination to enable a streamlined connection to the design workflow (Autodesk, 2020). The platform negates single point applications and unifies building project data, and consequently, aggregates data to provide transparency to the project team to make design practices more accountable by improving visibility in real time (Hardin & McCool, 2015). BIM 360 also encapsulates Industry Foundation Classes (IFC), which is a global standard for describing, sharing and exchanging information on building and facility management (Coates & Arayici, 2014).

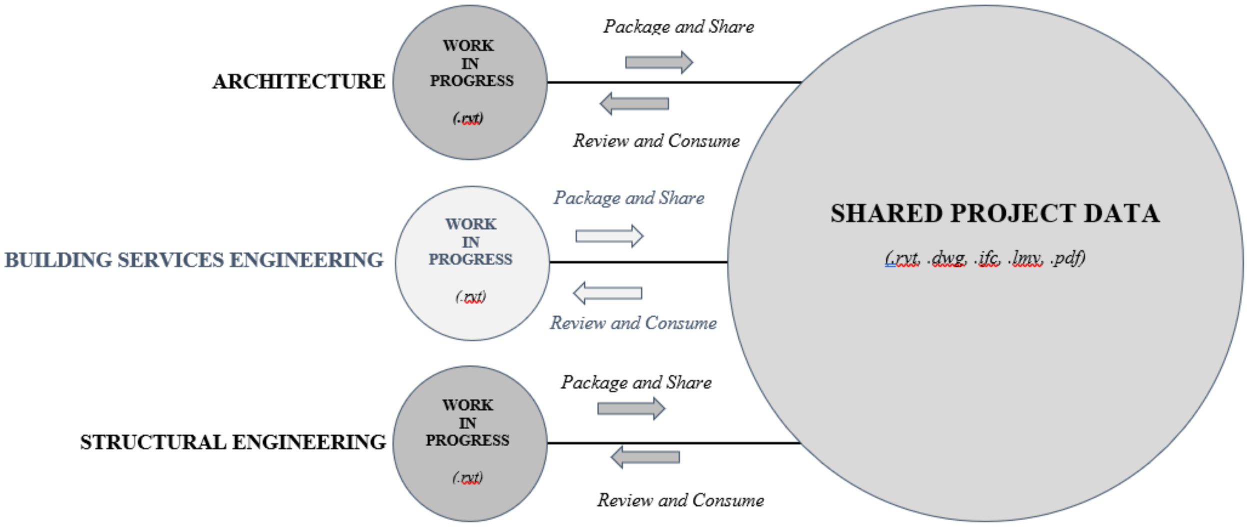

Figure 24 *BIM 360 design (Autodesk, 2020)*

2.4.3.2.6 BIM AND COBIE

The importance of multidisciplinary Construction-Operations Building information exchange (COBie) to setup and deliver digital facilities management data during the design and construction stages is paramount. This methodology captures data, which is a *contracted information exchange* for projects, to initiate building facilities' operation promptly at handover and occupation stages (Nepal & French, 2016) (BIM Ireland, 2017).

Thus far, the Irish AEC industry lacks this compunction, where design practices do not have the necessary COBie skillset (BuildingSMART, 2020). COBie Standards have been adopted somewhat by Irish practice. However, the literature reports a wide range in the quality of data being delivered. Furthermore, an endeavour by management to adopt this digital construct should focus on practice knowledge and skills required for successful COBie deliverance (BuildingSMART, 2020). COBie requirements need to be clearly understood, communicated, and applied in practice to replicate the current document-centric handover delivery to information-centric, standards-based, real-time handover data capture (Fallon, 2013).

The learning objectives identified in Bloom's taxonomy hereof, *remembering, understanding, applying, analysising, evaluating* and *creating* can be adopted to facilitate practice to manage COBie delivery (Hyder & Bhamani, 2017) *(Figure 21).* If practice fails to embrace this strategic approach, it can lead to inefficiencies at design stage, and consequently, deficiencies at construction stage.

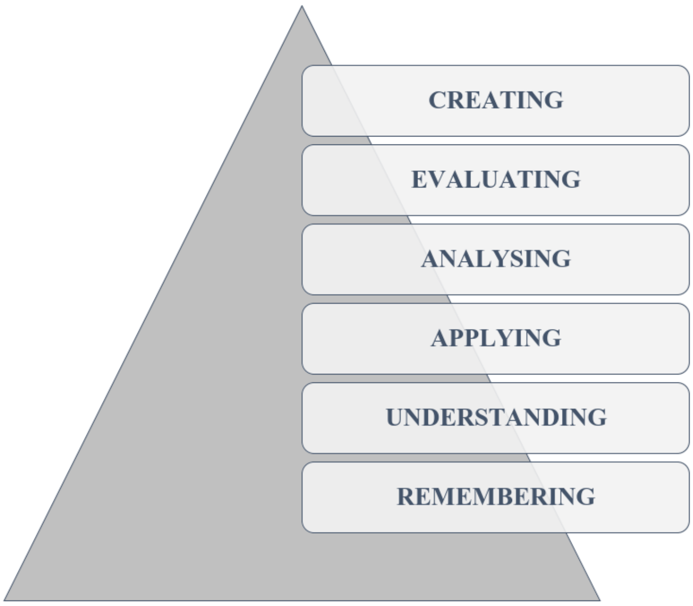

Figure 25 *COBie learning process (Hyder & Bhamani, 2017)*

2.4.3.3 DIGITAL GOVERNANCE

The AEC sector is a cornerstone of the world economy with annual revenues nearing 6% of global However, productivity has stagnated for decades, and design practice management has been slow to innovate. The industry is now ripe for change, and is set to embrace evolving digital technology with BIM at its central core. The direct effect is expected to reduce project lifecycle costs by almost 20%, and substantially improving design, completion time, quality, and safety (McAuley, Hore, & West, 2019).

Globally, digitalisation combined with collaborative processes are gradually transforming design, construction, commission and interaction with the built environment. Design decisions are made in days not months with open 3-D format models validated by machines for compliance, Practice is now moving from paper silos to digital tools, collaborative platforms and integrated ways of working. The future of the built environment is connected, well-planned and well-designed (Li, et al., 2014). Indeed, the future *internet of buildings* is driven in practice by integrating design and information leading to an effective digital transition (National BIM Council, 2018). With local government now promoting digital technology innovation, practice is reluctantly developing new skills (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016).

As familiarity and maturity increases in such digital constructs, BIM is set to influence a new generation of BSE practice (British Standards Institute, 2019). Thus far, the overall and practical effectiveness of BIM utilisation is difficult to quantify and justify. Undoubtedly, the wider use of technology, digital processes, and higher-skilled practices contribute greatly to the economic, social and built environmental future. By implication, the adoption of BIM represents BSE practices' moment of digitalisation (EUBIM, 2017).

The UK AEC industry has been implementing a clear government and industry driven Construction Strategy that aims to raise the level of design and construction, reduce waste, improve delivery, reduce capital expenditure, reduce carbon, and, most importantly, develop an industry that is world class in its application of modern methodologies and digitalisation. Central to this ambition is the adoption of information rich BIM technology processes (HM Government, 2015). However, the Irish government is lagging behind this endeavor, particularly with regard to the delivery of privately funded projects. Unless the AEC industry works in a BIM environment, it is likely to find itself at a serious competitive disadvantage.

On the contrary, the Irish Policy Advisory Board has placed a strong emphasis on BIM as a means to help bring about innovation in practice (Forfás, 2015).

It is no secret that the Irish AEC industry is changing. By rethinking the way digital technology plays a role in current BSE practice, it is imperative that management establish radical modernisation by connecting with market-leading digital expertise to leverage the scale to deliver innovative, differentiated solutions, boost performance, and ultimately grow business. Remarkably, the Irish government has not yet afforded adequate leadership in diffusing BIM, and has failed to provide online supports or reviews of the suitability or provisions made for developing public construction contracts.

More initiatively, the National Standards Authority of Ireland (NSAI) has recently developed a BIM certification program aligned with the publication of IS EN 19650: *Part 2* to provide an internationally recognised standard for BIM, where higher education institutes endeavour to upskill future and current practitioners (McAuley, Hore, & West, 2019).Whilst Ireland has recently shown a steady increase in some aspects of BIM maturity, whereby barriers to its implementation are inherent *(Figure 26)*, but it requires investment of knowledge in standards and protocols, training in new software platforms, and financial investment to access these digital tools (NBS, 2019) (World Economic Forum, 2018).

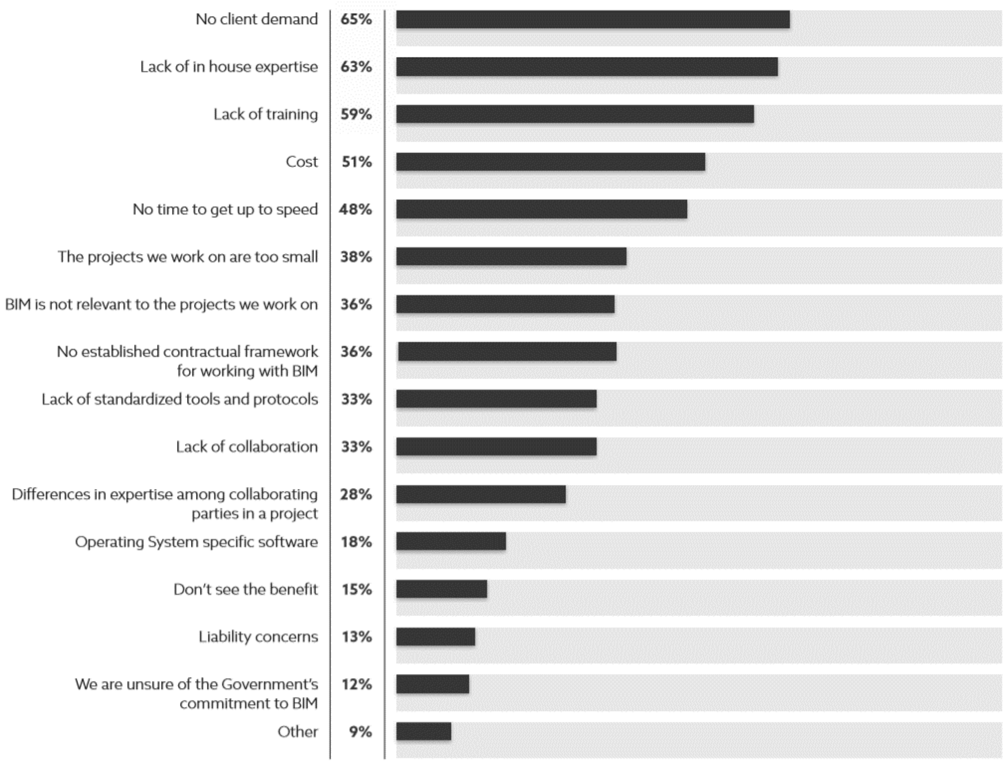

Figure 26 *Main barriers to BIM implementation (NBS, 2019)*

Henceforth, the National BIM Council of Ireland (NBC) is driving a roadmap (2018-2021) to implement digital design, construction and operation of built asset. The ambition to create an AEC industry that is more integrated with the multidisciplinary built environment to attract a diverse range of people to new positions that don't currently exist (Construction Industry Federation, 2018). The literature identifies that Ireland ranks high in technology infrastructure and education and learning, but lowly ranked from an objectives, regulatory frameworks, standardisation parts and measurement and benchmarks perspective (World Economic Forum, 2018) *(Figure 27).*

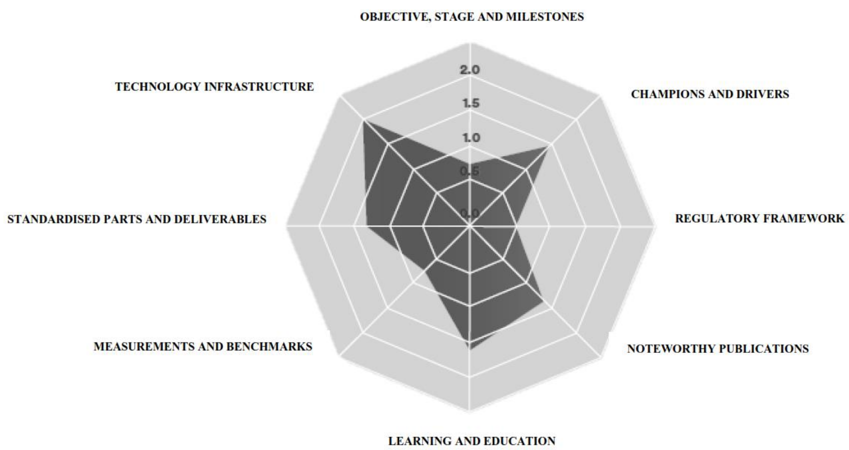

Figure 27 *Macro maturity components model in Ireland (National BIM Council, 2018)*

The macro diffusion responsibilities model assesses and compares the roles played by stakeholders in facilitating diffusion of BIM digitalisation, which identifies technology driver as an influential player, while the educational institutes had a much higher BIM diffusion compared to policy makers. Both construction organisations and *communities of practice* are also identified as key players (National BIM Council, 2018) *(Figure 28).*

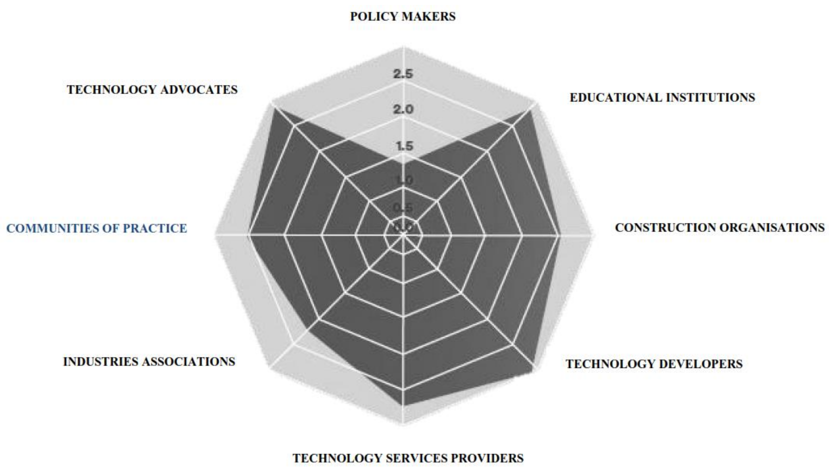

Figure 28 *Macro diffusion responsibilities in Ireland (National BIM Council, 2018)*

Successful BIM adoption will require a high level of collaboration, most notably, by increasing use of open standards for data sharing, with a concerted effort upskill existing practice by changing its culture to support new processes (World Economic Forum, 2018) *(Figure 29).* BSE management needs to take responsibility for upskilling their practice. The time is now.

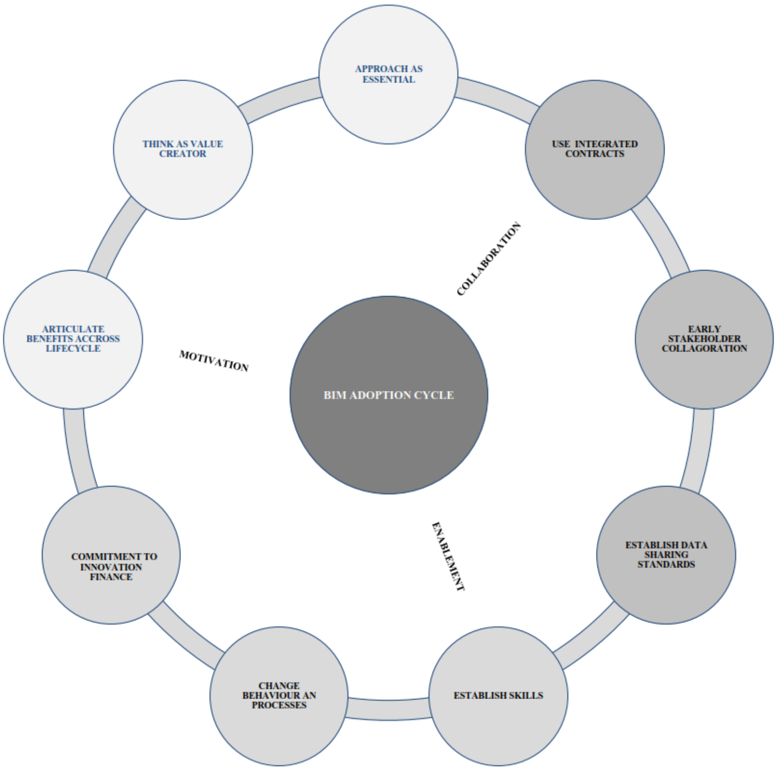

Figure 29 *BIM adoption cycle* (World Economic Forum, 2018)

2.4.3.4 DIGITAL TRANSITION

The future is already here, it's just not very evenly distributed – William Ford Gibson

Unlike other trades, the Irish AEC industry is slow to adopt new technologies, and has never undergone a major transformation. Thus far, the take-up of digital process methodologies has been limited, and many practices that have adopted them have failed to apply them successfully (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016).

From a BSE perspective, digitalisation can improve the design process by facilitating multidisciplinary team parallelisation to merge designs, and enhance efficiency at construction stage by detecting and averting potential interference and by optimising installability. The operational phase benefit from digitalisation exploits the advanced performance analyses conducted in the design stage, which utilises the building information received by the operator (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016).

BSE management is now in a position to pioneer the design process, and learn to leverage the comprehensive portfolios of digital technologies, or face being left behind. The Irish AEC industry is approaching digitalisation at different speeds and in different ways. BSE practice is ramping-up their digital agenda to succeed in this challenging environment and reap the benefits from digitalisation (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016). However, a technology-driven design practice will often require uprooting of entrenched behaviours and customs. BSE management is now in a position to lead and build their teams by rolling out new digital competencies, establishing the technological foundation, and disseminating digital skills across their practice.

As a key project owner and regulator, the Irish government must make conditions more conducive, realising digital technologies to their full potential as the industry norm, and creating a fertile environment for digitalisation through possibly joint industry-academia funding and amending curricula in higher education institutes (Hore, McAuley, & West, 2019). If management wants to contribute to redefining the competitive landscape, it needs to seize the opportunity soon; practices that continue to ignore this digital wave will struggle to survive (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016).

The Irish government recognises the importance of digital innovation to address adverse encounters such as the lack of research and development and weak use of digital solutions (GCCC, 2017) (National BIM Council, 2017). As the Irish AEC industry negotiates around a drastically altered practice environment, projects are increasingly complex. Being digitally-enabled provides practice management with centralised support regardless of location by remotely performing ongoing technical health checks, thus ensuring accurate up-to-date information is accessible in near real-time *(Figure 30).* This illustrates the potential of BIM throughout the project lifecycle, which is achievable through the implementation of standard processes for a digital plan-of-work (Underwood & Bew, 2010).

In addition, the literature infers how the implementation of BIM not only systematises, but also simplifies the design process. The potential of digitisation in offering structured streamlined design processes is vividly becoming a reality. The comparative evidence indicates how unnecessary design iterations can be reduced and projects delivered in less time and with less cost than without using state-of-the-art BIM technologies (Whyte & Hartmann, 2017). However, despite evidence that digitisation can improve processes, there is a requirement to thoroughly balance how digitisation methods are implemented in practice.

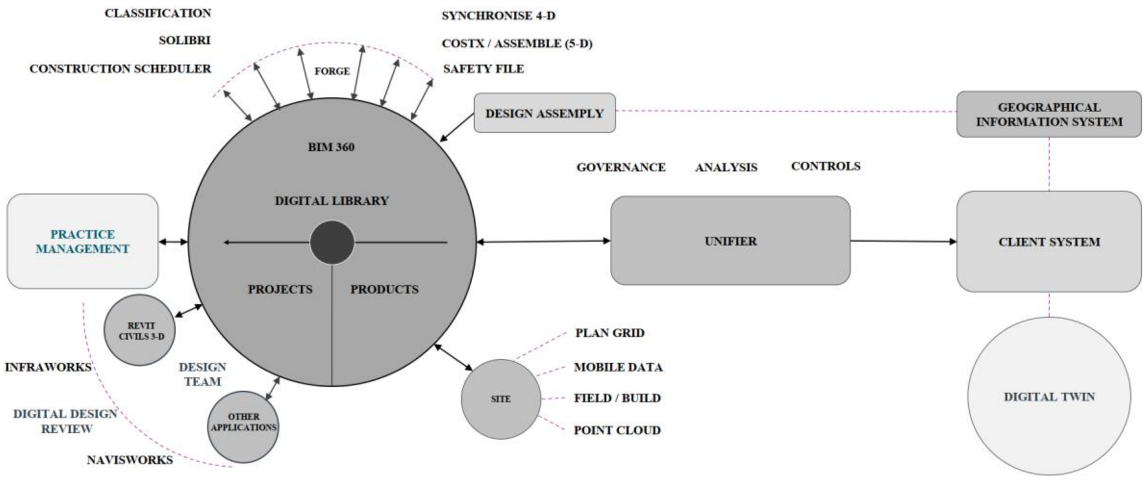

Figure 30 *Digital delivery adaptation to BSE practice* **(AECOM, 2021)**

A strategic leap with BIM could offer a more structured digital alternative way of working. As the term *building information modelling* may not be an accurate description to the managerial construct, a modified term *building information management* is more pertinent. The onerous task of managing a design process through several, separately produced, separately managed, 2-D documentation is inefficient, as opposed to managing the design of a building once through intelligent 3-D objects assembled in a federated model *(Figure 31).*

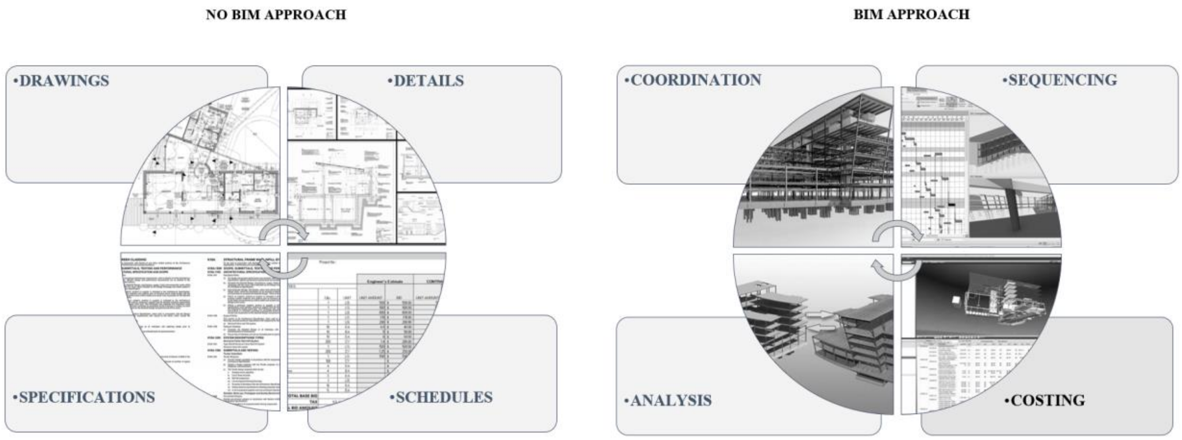

Figure 31 *Efficient BIM approach*

Ultimately, productivity in the AEC industry has not increased in the past 40-years when compared to the manufacturing industry, which suggests that an inherent productivity gap exists. The key differentiator between both industries is that manufacturing embraces a *measure-twice* approach that the AEC industry could learn, thus executing construction exactly as per the digital design model *(Figure 32).*

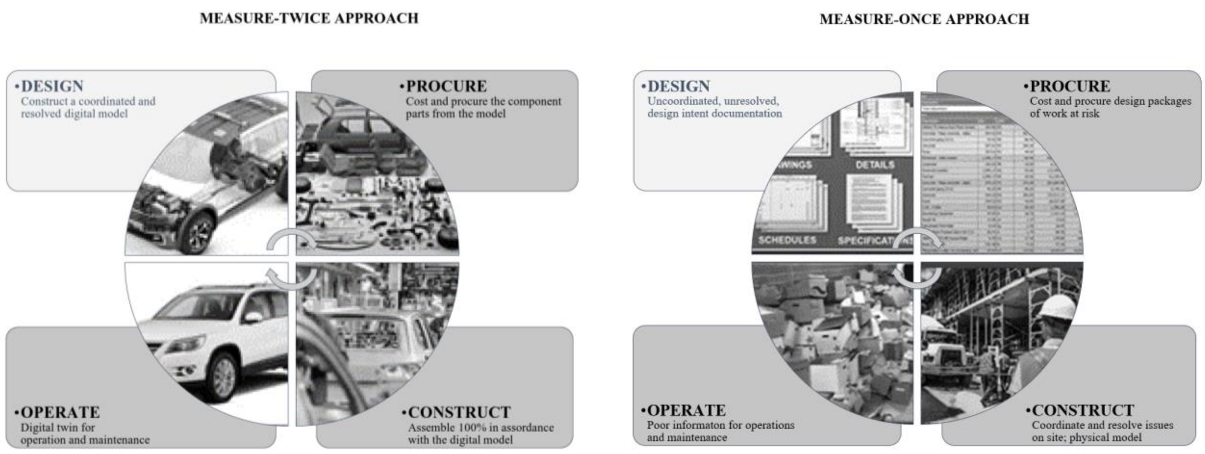

Figure 32 *Manufacturing and AEC industry delivery*

By digitising the building environment, BSE management requires a true understanding of this *building information management* process in the context of initial input and effort to deliver an efficient design process *(Figure 33).*

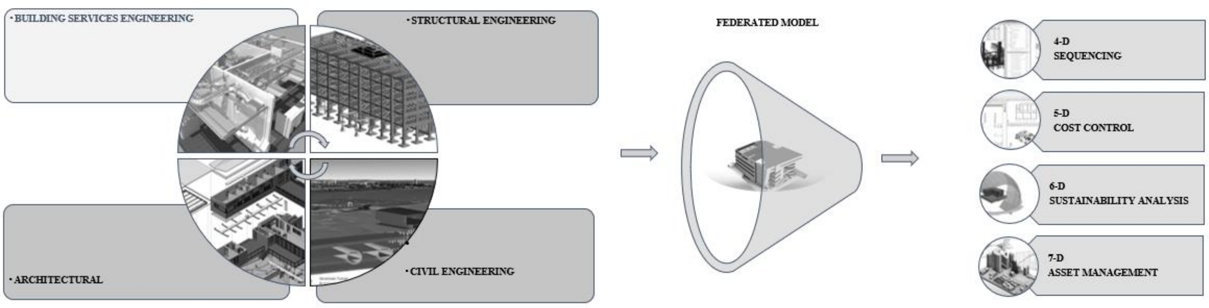

Figure 33 *Level 2 BIM approach*

The status-quo in Irish BSE practice cannot continue. Shifting the way practice produces and manages information at design stage has the potential to mitigate 30% cost waste at construction stage (Aziz & Hafez, 2013). The Irish AEC industry needs to follow the UK in their endeavour to deliver 50% *better*, 33% *cheaper* and 50% *quicker* buildings (McKinsley Gloal Institute, 2017) *(Figure 34).*

This digital transition will require practice to collaborate and follow defined processes and standards. Management need to understand their role, and how they control the production and exchange of digital information for practical use. Working in a standardised manner is the reason that processes work well. A highly efficient digitised design process depends on highly standardised machine-readable data to promote practice excellence (National BIM Council, 2018).

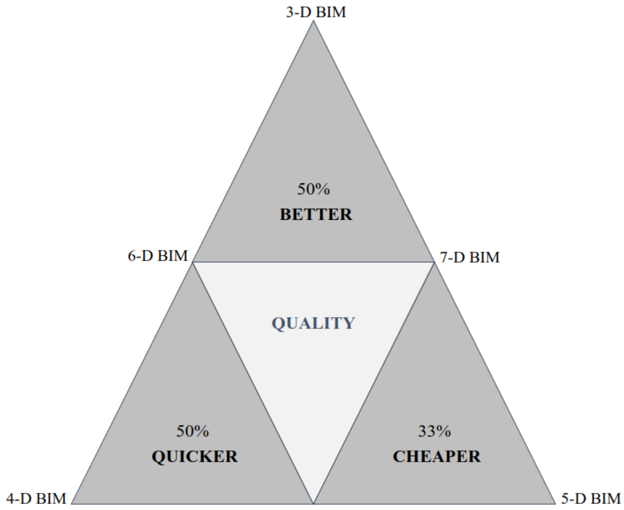

Figure 34 *What the clients want* (HM Government, 2013)

The BIM process, ISO 19650; *Parts 1 & 2*, was published in 2018, and adopted by the European Standardisation Organisations, and subsequently, adopted by the Irish AEC industry ISO 19650; *Parts 3 & 4* was also published in 2020. The construction industry council (CIC) has recently produced commercial and legal instruments to include BIM stipulations appended to each contract appointment, which defines the roles and responsibilities, copyrights, licence to use information, limit of liability, public indemnity insurance, and moreover, outline the scope of service for information management *(Figures 21 & 35)*. Every building component will have a 3-D object in the BIM model with a set of data properties attributing to that object and a set of documentation related to that object.

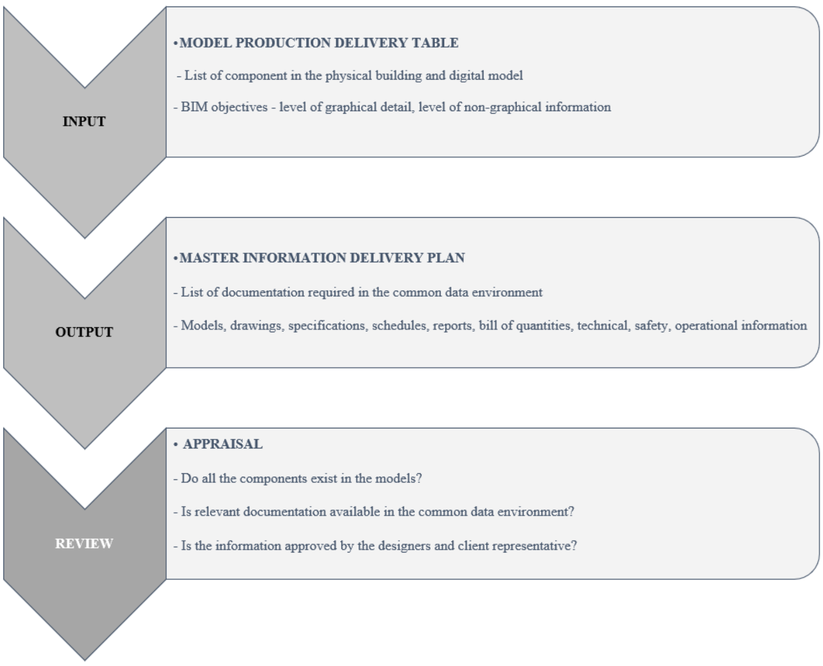

Figure 35 *BIM information management process*

The capital delivery stage is short compared with the operational stage, whilst the cost of implementing such a digital strategy increases proportionally the longer digitisation has not being adopted. To this end, management needs to truly adopt BIM to bring transparency and accountability to the BSE design process.

2.4.3.5 DIGITAL PRACTICE

Innovative management by digitally transforming the BSE design process also has the potential to encourage practice and clients make better-informed decisions by using automated knowledge-sharing and generative design techniques that provide multiple design options earlier in the design process. For instance, providing detailed 3-D plantroom information with scheduling at scheme design stage, rather than at detailed design, means cost plans can be tested earlier and realistic financial models can be developed from the start, thus minimising risk to the programme and cost impact of design changes (Sacks, Eastman, Teicholz, & Lee, 2018). Through standardisation of digital advancements, BSE management is in a position to influence an industry-leading approach to digital engineering, which permits practitioners to make better decisions with more information, thus producing highly-detailed, construction-ready designs that will improve technical co-ordination and productivity of the wider design team, reducing contractor design, requests for information schedules, change requests and shorten construction programme (Schober, 2016).

Digital design tools have the potential to reap 20% savings in design practice (Agarwal, Chandrasekaran, & Sridhar, 2016). Such advances in digital technology have brought new ways to optimise project delivery, increase productivity and create efficiencies throughout the design and construction stages (Parsons, Mischke, & Barbosa, 2017). Harnessing the processing power of digitalisation could transform the design process. Design-construction optimisation tools to automate sequencing through enhanced value engineering, understands individual design tasks, and the dependencies between them, enabling an informed review of multiple scenarios to find the optimal sequence. This improved planning capability is anticipated to create schedule reductions of up to 15% on a typical project (Lawlor, 2017).

The adoption of a digital workflow strategy in BSE practice could support project delivery from inception to completion, thus ensuring benefits from digital best practice, workflow and governance throughout.

Through a digital-healthy-start, practice can mobilise digital skills early on a project to ensure that trustworthy technologies are in place from the start. This strategy improves productivity in design practice between 2-10% by facilitating greater multidisciplinary coordination, reducing design stage rework, reducing installation costs due to fewer site clashes and issues, and improving stakeholder engagement (Byrne, 2018). BIM digital reviews also bring different design disciplines together to establish issues early and increase program certainty. This collaborative approach commands management to take an active role in setting the tone, and establishing an integrated digital team environment by adopting six crucial steps *(Figure 36).*

Figure 36 *Collaborative digital working environment* (AECOM, 2020)

Defining *principles and values* early is a critical step in developing common goals. Creating *policies and procedures* in collaboration with stakeholders, and more importantly, using them consistently to organise a basis of policies at the start of a project, thus contributing to effective design. This fosters an integrated document collaboration and reporting using cloud hosting for design documentation. This common technology platform enables the greater design team to better communicate and collaborate across scopes and disciplines, thus creating a path that links practitioner success with the success of the project.

The practice-based case study in this inquiry standardised a digital platform to ensure seamless and consistent reporting, document control and communication. The researcher integrated with the client and brought together six design consultants under a *Project Excellence Team* banner with all practitioners referring to themselves as part of this team rather than an employee of a practice, designing as one unified team to deliver a public contract with a capital expenditure of €86M.

2.5 PRACTICE INNOVATION

The adoption of any new construct or idea is never instantaneous in practice. Instead, it is dependent on management who are more apt to embracing new innovates. The *theory of diffusion of innovation* not only validates this fact, but also demonstrates that management who are more willing to foster innovation have different characteristics when compared to their practice peers who often adopt innovation later (Walaseka & Barszczb, 2017) *(Figure 37).*

Innovators are somewhat portrayed as being venturesome with a keen interest in new ideas and willing to take risks. On the other hand, *early adopters* represent opinion managers who enjoy management roles, and embrace change opportunities. They are already aware of the need to change, and therefore, they are very comfortable adopting new ideas. Conversely, *early majority* are rarely managers who adopt new ideas before the average person, and typically need to see evidence that the innovation works before they are willing to adopt. *Late majority* is sceptical of change, and will only adopt an innovation after it has been tried and successfully adopted by the majority. Furthermore, *laggards* are bound by tradition and very conservative. They are sceptical of change and are the hardest group to persuade (Maloney, 2010).

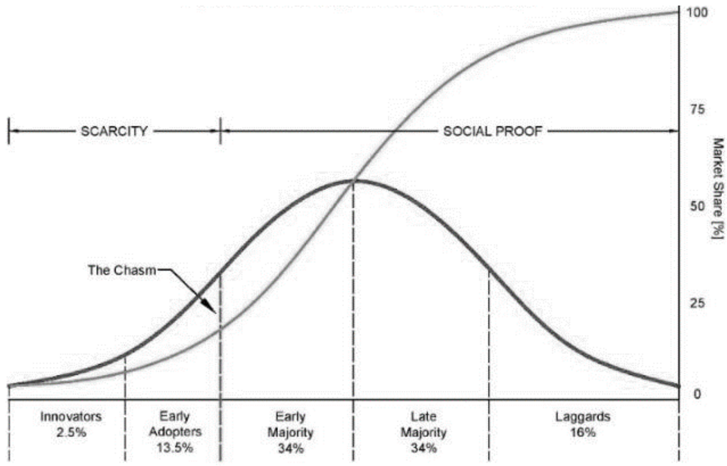

Figure 37 *Rogers' law of diffusion of innovation (Health, 2016)*

The chasm occurs at the transition between the *early adopters* and the *early majority*. Once 16% adoption of an innovation is reached, design strategy changes from one based on scarcity to one based on social proof. Moreover, the tipping point occurs when mainstream practice begins to adopt the innovation (Maloney, 2010).

Thus far, the conceptualisation approach to improve BSE practice by embracing digitalisation is having a profound effect in the AEC industry (Moreno, Olbina, & Issa, 2019). Whilst this development is conceptually independent and separate, there are synergies between practice and digitalisation that extend beyond the essentially circumstantial nature of them approaching maturity together. The literature reveals that a high number of interactions exist between both, which suggests that the respective parallel improvement and adoption would be in small steps (Sacks, Koskela, Dave, & Owen, 2010).

2.6 THEORETICAL FRAMEWORK

The literature has identified practice inefficiencies at design stage, which are found to be a major source of deficiencies at construction stage, even to the extent of undermining practice management (Akbıyıklı & Eaton, 2011). Their direct consequence imposes practice dysfunction, whereby it is estimated that an additional 40-50% of the total work hours of a project are required to rectify (Kostela, Huovila, & Leinonen, 2002) *(Figure 38).* This critical review takes cognisance of practice in the context of *people*, *processes* and *technology*, and demonstrates the fragmented nature and complexity of BSE management.
Its appraisal primarily focuses on theoretical concepts for the basis of promoting a sustainable design process through effective management, thus potentially improving the performance and technical efficiency of practice (Austin, Baldwin, & Newton, 1994). This review has also facilitated a greater understanding of the design and construction stages with an appreciation for managerial research, which underpin the fundamental tenets of this practice-based research.

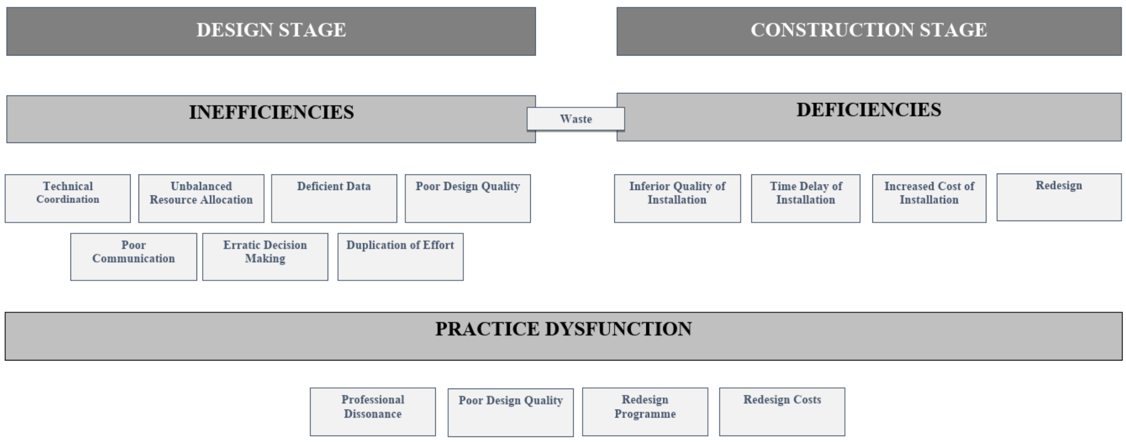

Figure 38 *Theoretical findings*

The collaborative nature of BSE practice disguises many of its underlying properties, which are multidisciplinary in nature. Therefore, it is imperative to develop a theoretical framework, which supports the evidence-based practice of the interaction between management and practice to establish a modern design process. A framework of this nature would systematically support clear interdisciplinarity and interactivity between management and practitioners, where current academia and practice is somewhat sceptical *(Haigh & Amaratunga, 2010)*. Moreover, this endeavour to synthesise practice-created knowledge from practice-based research and academia implies that knowledge-creation, knowledge-use and education are highly interdependent *(Eraut, 1985)*.

Moreover, this research in the built environment is a systematic investigation comprising creative work, methodical in procedure, to increase the stock of *new* knowledge with an intention to devise a new management framework applicable to BSE practice. To this end, a critique of literature in *engineering management* was strategically synthesised in the context of the respective practice, and it is here that a theoretical framework has evolved. The practical relevance of this framework has enabled the researcher to impose a sense of reality and coherence in the context of his research, whilst coming to terms with their professional experience (Cohen, Manion, & Morrison, 2000), thus framing the main components to be tested and the presumed relationships amongst them (Miles & Huberman, 1994). It is theorised that a greater understanding by management of the dichotomy between the design and construction stages will pave the way for practice to adapt new measures to improve the design process (Mitchell, Frame, & Coday, 2011).

Thus far, the body of engineering design knowledge within the context of people, processes and technology is beyond the capacity of management, and has led to the division of BSE practice (Kleinsmann, 2006). In addition, considering the escalation in complexity of project delivery, practice now commands a high level of collaboration, cooperation, and coordination, where its design process has inevitably become disjointed (Knotten, 2017). Design process challenges have been the principle contributor to failure at construction stage, and increasingly more at operational stage (Fischer, Khanzode, Reed, & Ashcraft, 2017). These challenges coupled with the complexity of the design process have initiated management to provide an environment for efficiency to improve practice. However, considering the literature, it is clear that management has not been proficient in this regard (Borgstein, Lamberts, & Hensen, 2018).

Management considers design as a technical activity, which appears to be the root cause of problems faced by current BSE practice. To counteract this narrow technical understanding of design, social concepts are also theorised. This theory-driven proposition is expected to complement practice transformation (Pikas, Koskela, & Seppänen, 2019). It is also contended that poor practice results from the lack of a common underlying theory of design management.

To advance practice, the researcher is cognisant of the nature of design and design management processed, but also considers the broader phenomenon of digitalisation as instrumental to the management proficiency and success of the design process (Koskela, Ferrantelli, Niiranen, Pikas, & Dave, 2018). Accordingly, a unified theory of management in BSE practice has emerged, where its intent focuses on people, processes and technology to improve the design process (Pikas, Koskela, & Seppänen, 2019) *(Figure 39).*

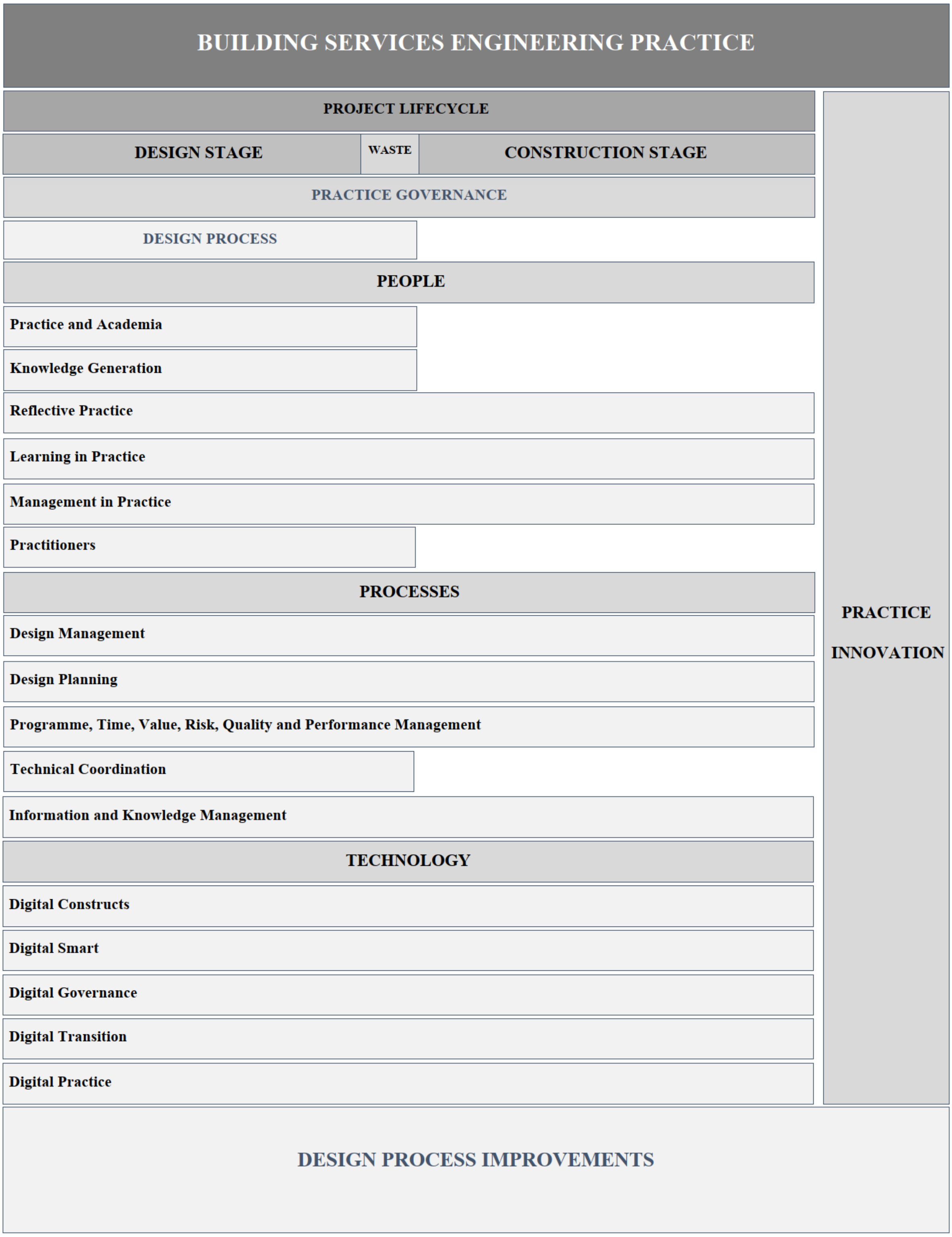

Figure 39 *Theoretical framework for BSE management*

Despite tentative in nature, this theoretical framework justifies and informs this practice-based qualitative research design by refining the research aim and selecting appropriate research methodology and methods (Kuechler & Vaishnavi, 2011). It also serves to extrapolate pertinent interview questions from the inherent literature review, thus identifies potential validity threats to the research conclusion (Maxwell, 2013).

CHAPTER 3 RESEARCH METHODOLOGY AND METHODS

3.1 INTRODUCTION

A discipline is established by a unique body of knowledge produced through research. Only by the use of appropriate methodologies and methods of research applied with rigor can the body of knowledge be advanced with confidence (Amaratunga, Baldry, Sarshar, & Newton, 2002). Research methodology sets out the principles for conducting research that evolve from the paradigm assumptions guided by decision-making. This inquiry takes cognisance of the relationship between the researcher and the researched, epistemological assumptions about the nature of knowledge with the legitimate knowers, the extent to which subjective meanings are valued and incorporated into the research, and how the researcher is incorporated into the process of analysis and presentation of findings (Berman, Ford-Gilboe, & Cambell, 1998). The subjective interpretations of this evidence-based research is not just anecdotal, but instead required the researcher to rigorously collect, make sense of, and analyse data (Kelly & Bowe, 2011) .

Methodological assumptions infer how the researcher procures knowledge in a systematic manner driven by their ontological and epistemogical beliefs, which comprises the research method with variant degrees of subjectivity and objectivity (Ratner, 2002). Methodologies justify methods, and methods produce knowledge, and therefore, methodologies have epistemic content (Carter & Little, 2007). The philosophical differences between the two dominant research paradigms in the built environment are qualitative and quantitative (Christensen & Johnson, 2008). Researchers are often overwhelmed by the plethora of research methodologies, making the selection difficult of an appropriate research design for their discipline (Groenewald, 2004). Accordingly, management has been subjected to much debate about the most appropriate research approach (Gill & Johnson, 1997). The complexity of managerial research and attempts to apply an appropriate research methodology is partly responsible for the limited success of management science (Checkland, 1981).

Designing a research plan is a critical thinking process, the outcome of which is directly related to the methodology adopted (Trafford & Leshem, 2012) (Singh & Bajpai, 2008). Moreover, the research process map, which encapsulates the research methodology, is guided by the researcher's philosophical beliefs and research questions (Dave, Koskela, Kiviniemi, & Owen, 2013) *(Figure 4).*

It also guides the researcher from conceptualising their practice-based problems, the logical sequence that connects the empirical data to the research aim, and ultimately to the conclusion (Yin, 1989) (Punch, 2000) *(Figure 4).*

This practice-based inquiry favours a strong qualitative research approach, by which the research is conducted in its natural setting, whereby the researcher is active in collecting the data. As the focus is on contextual conditions in practice (Yin, 2003), a case study facilitates the researcher's implicit and explicit understanding of the contemporary phenomena in its natural setting (Grix, 2004). The researcher has selected an *instrumental* case study design to play a supportive role in this regard (Stake, 1995) by testing the theoretical framework.

The theoretical path focuses on understanding empirical BSE practice, and applies triangulated data collection primarily from fifteen *interviews*, and also supplemented from *document analysis* and the researcher's *reflective journal,* to test the various components of the theoretical framework (Brinberg & McGrath, 1985). Propositions were derived from this theory-test to produce a *revised* framework (Cavaye, 1996). The more rivals and alternative explanations that the analysis addresses, the greater the credibility of this study (Yin, 2003), thus contributing to the body of knowledge in the discipline. Consequently, a broader dataset was procured by conducting *interviews* with external seasoned professionals to test the validity of this framework. The traditional *research onion* was deployed for this inquiry, which provides an effective progression through which the research methodology is designed (Saunders, Lewis, & Thornhill, 2007) (*Figure 40*).

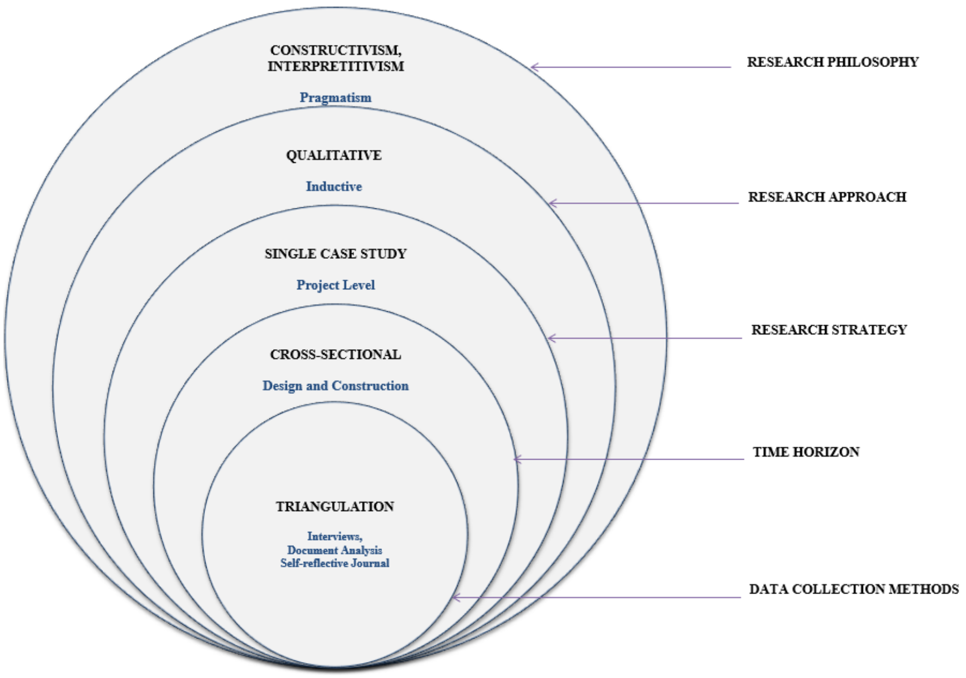

Figure 40 *Stages of inquiry* (Saunders, Lewis, & Thornhill, 2007)

Its usefulness lies in its adaptability for practically any research methodology, thus creating a series of stages under which the different methods of data collection are understood, whilst illustrating the steps by which a methodological inquiry can be described (Burmeister & Aitken, 2012). The *research philosophy* in the inquiry requires definition from the outset to create a starting point for the appropriate *research approach*. The *research strategy* is then deployed followed by establishing an appropriate *time-horizon*, whereby the data is collected.

The Biglan disciplinary model represents a structure for academic and practice-based research in the built environment on a sequence from pure/applied *(explicit / implicit)* and hard/soft *(paradigmatic\non-paradigmatic)* matrix (Chynoweth, 2009). To this end, managerial research is described in the *design* and *management* quadrant of the built environment profession, and identified as a *soft-applied* discipline, whereby its ingredients comprises of cogitative, affective and behavioral components, thus typically favouring a qualitative research methodology (*Figure 41)*.

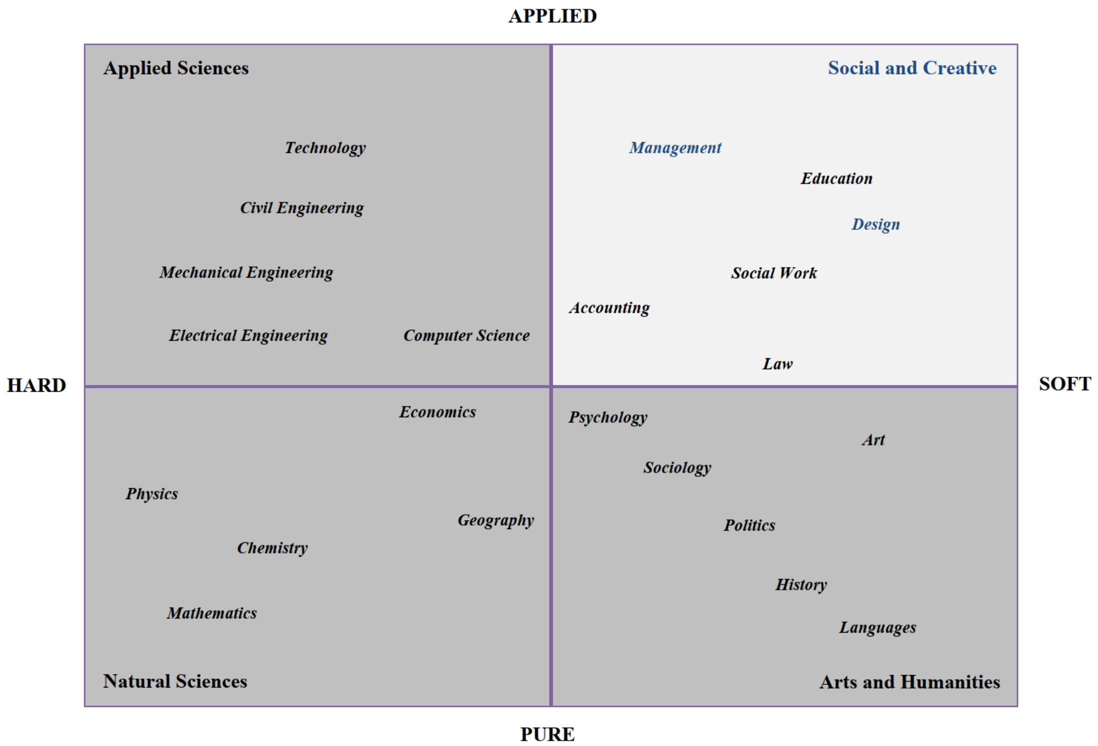

Figure 41 *The Biglan disciplinary model* **(Chynoweth, 2008)**

However, this research is intended to accomplish something greater than understanding BSE management. It is about advancing managerial effectiveness by developing a management framework to improve the design process through the proficient convergence of people, processes and technology in practice.

3.2 STATEMENT OF RESEARCH AIM

The literature often compares attitudes towards managerial inquiry, and infers that practice management believe research is initiated by academic researchers often insufficiently familiar with the managerial culture, and therefore, lacks credibility (Gill & Johnson, 1997). From an academic view, it is suggested that managerial inquiry adopts a naïve and unreflecting empiricism, thus suggesting that researchers should be provided with a more sophisticated understanding of the epistemological position (Whitley, 1984). However, the researcher of this inquiry is uniquely positioned as a researching professional who is driven by a desire to solve a real practice problem. The research design in this inquiry is by no means a clear-cut process following a neat pattern, but a complex interaction between the conceptual and empirical world (Bechhofer, 1974).

The nature of BSE management is both purposeful and goal-oriented, which aspires to effectively coordinate all resources, processes and design activities in practice. This research aims to develop a management framework to improve the BSE design process by the proficient convergence of people, processes and technology. In this regard, the following objectives with innovative methods were justified as key research enablers:

I. Synthesis of BSE management theory
(Method: *Conduct a literature review of design management and project management to provide a theoretical overview of engineering management)*

II. Develop a theoretical management framework
(Method: *Conduct a literature review to exemplify how engineering management can improve the BSE design process by the efficient convergence of people, processes and technology, and its dichotomy at design and construction stages)*

III. Examine and test components of the theoretical management framework with empirical data to devise a revised framework
(Method: *Conduct a cross-sectional instrumental case study of a practice-based project to gain insight to real engineering management at both design and construction stages. Empirical data principally sourced and analysed from interviews with 15-BSE professionals, and supplemented by case study project documentation, and the researcher's reflective journal)*

IV. Test the validity of the revised framework with empirical data
(Method: *Test components of the revised framework with empirical data sourced and analysed from interviews with 5-seasoned professionals in the Irish BSE industry)*

V. Extrapolate a conclusive BSE management framework
(Method: *The interpretivism paradigm is adopted to put data analysis in context, where the researcher has relied heavily on interviewing, observation and analysis of existing knowledge)*

3.3 RESEARCH PHILOSOPHY

(This section shall be read in conjunction with Figure 4).

3.3.1 PHILOSOPHICAL STATMENT

A discussion on philosophy is essential before embarking on research. Ontology signifies the belief about the nature of reality. In philosophical terms, it refers to the study of existence and the fundamental nature of reality. Therefore, beliefs about the nature of reality determine what can be *known* about it (Amaratunga, Baldry, Sarshar, & Newton, 2002).

Epistemology and methodology are driven by ontology beliefs, whereby the former is more philosophical in nature, and examines the relationship between knowledge and the researcher during the inquiry, thus referring to *what* is known and *how* it is known. The ontological belief dictates the objectiveness of the relationship between the researcher and *what can be known.* Epistemology may be thought of as justification of knowledge, which guides methodological choices from an axiological perspective.

Methodology is shaped by the research objectives, questions, and the research design. Methodologies prescribe choices of method, and resonate with academia to encourage or discourage the use and development of theory. Research methods are constrained by methodological and epistemic choices. It is argued that epistemology provides a potential connection between practice-based research and formal theories of knowledge (Carter & Little, 2007).

From an ontological perspective, there are two perceptions of reality, *realism* and *relativism*. Whilst realism is a belief that reality exists driven by natural laws, it is objective and independent of theories of human beliefs or behaviour, and exists even if it not yet known; it is context free. In this mind-set, realism is the ontological perspective within the quantitative or positivist paradigm of research (Taylor & Medina, 2013). Since such a reality exists, the epistemology within positivism is objective in nature (Mack, 2010). This objectivity means that the researcher maintains distance from the researched in order to prevent influence on the results. The methodology in this paradigm is experimental and manipulative in nature, whereby the hypothesis is tested and quantitative methods are viewed as superior. Structured measures may be taken to govern anything that may influence the research inquiry.

The strongest contrasting ontological perspective to realism is relativism. Research founded on relativism searches for meaning in the experiences of individuals. Relativism is a belief that a reality cannot exist without context. Relativists believe that there are multiple mental constructions of reality. Such realities are influenced by experiences in social interactions. Therefore, it is suggested that each individual has their own reality, which is considered truthful. Relativism is the ontological perspective within the qualitative or constructivist paradigm of research. Constructivists reject the notion that subjective reality exists. The epistemology considers the researcher and participants as co-creators of the findings, which involve the interaction between the researcher and the participants (Soini, Kronqvist, Huber, 2011). By conducting interviews using this qualitative method suggests that appropriate findings may be sought.

Critical theory research represents a further shift from positivism than *interpretivism*, which is founded on the historical realism that essentially proposes what is seen as real (Nunes, Annansing, Eaglestone, & Wakefield, 2005). Undoubtedly, this paradigm suggests relevance and reliability to the research methodology in this inquiry. Moreover, the epistemology in this paradigm is based on the interactions of the researcher and the researched with subjectivity, where the values of the researcher are considered a controlled influence on the findings. This methodology is based on dialogue that discovers findings through exchanging logical arguments.

Furthermore, axiology is a field of philosophical study involving the way *value* is set by researchers. The researcher who engages in axiology seeks to understand why participants hold any value over another value, or how those values react when used as judgments in both a vacuum and within any given culture (Brown & Coombe, 2015). This contributes to the development of the research methodology as it describes the position and role of the researcher, who brings implicit values, beliefs and experience to the research. However, there is a risk that participants' views could be considered less worthy than the informed researcher.

3.3.2 PHILOSOPHICAL POSITION

A fundamental question that challenged the researcher was to construct a philosophical position and orientation towards this inquiry (Dainty, 2008). A number of research paradigms were considered for their appropriateness to managerial inquiry. The epistemology within *positivism* is objective in nature, which opposes the real subjectivity of managerial research (Mack, 2010). In contrast, *constructivism* is the belief that researchers construct meaning based on interactions, whereby knowledge is not found, but constructed, recognising the importance of subjectivity, but not rejecting the notion of objectivity (Baxter & Jack, 2008) (Soini, Kronqvist, & Huber, 2011).

Constructivism argues that researchers generate knowledge and meaning from an interaction between their experiences and their ideas. Moreover, critical theory stresses the reflective assessment and critique of society and culture by applying knowledge from the social sciences. Adapting this methodology solely based on interactions between the researcher and the participants signifies its relevance to this inquiry. Equally *interpretivism* represents one of the earliest shifts away from positivism, where a theory cannot be proven, but a strong case can be made for it by disproving alternative explanations (Hermans, 2011).

Interpretivists do not believe it is possible to maintain absolute distance from the researched (Nunes, Annansing, Eaglestone, & Wakefield, 2005). Interpretivism relies heavily on naturalistic methods of interviewing, observation and analysis of existing knowledge. Interpretive methodologies encompass an experience in practice that acknowledges participant action as meaningful (Bevir & A. Kedar, 2008).

The core principles of research design were explored by mapping relative research approaches and methods to this inquiry. Traditionally, research paradigms dominate the researcher's pattern of thought to such an extent that they are passed on unquestioned and inherited from one researcher to the next (Porta, 2008). On the contrary, making practical use of new concepts requires intellectual effort. This deployment may prove problematic by implementation, as it is a consideration seldom adopted in the pertinacity of the built environment professional practice. By insinuation, management is assumed to suffer from knowledge deficiency due to their practice ignoring alternate research findings (Eraut, 1985). The benefit in bringing together practice-based researchers through the needs of their field is becoming progressive, where an integrated framework with more detailed practice activities and strategies can be debated (Barrett & Barrett, 2003).

Practical reasoning defines a distinctive standpoint of reflection, and is concerned with *matters of value* (Pitchard, 2018). The personal thoughts of the researcher and their research is characterised from a practical point of view by comparing with the standpoint of theoretical reason, which is concerned with *matters of fact.* The salient difference between both attitudes is that theoretical reasoning leads to impulsive beliefs, whereas practical reasoning may lead to changeable intentions, which suggest their relevance to this inquiry (Bratmann, 1988). Thus far, the ability to meet doctoral research criteria is imperative given that an implied learning outcome is the ability to engage in high-level research as an autonomous researcher (Deniclo & Park, 2010).

3.4 RESEARCH APPROACH

The methodological choice in this inquiry is determined not only by the nature of the research topic being explored and the resources available, but by the particular education and professional practice to which the researcher is exposed (Gill & Johnson, 1997). The complexity of this managerial research and attempts to apply an appropriate research methodology is responsible for the limited success of management science (Checkland, 1981).

A quantitative research design is concerned with defining an epistemogical methodology for determining the truth-value of propositions, which allows flexibility in the treatment of data in terms of comparative analysis, statistical analyses and the repeatability of data collection in order to verify reliability (Almwber, 2018).

It is strong where processes can be reduced to variables by investigating people involved and situations. However, quantitative research tends to take a snapshot of a situation. It is noted that the practice-based environment in which this inquiry is conducted is often affected by a dynamic activities. Although a quantitative approach is commonly adapted by researchers in the built environment, it was foreseen that the research objectives in this inquiry would not be feasible. Notwithstanding this, it was anticipated that the research outcome would not not quantifiable, and therefore, this approach was considered inappropriate (Amaratunga, Baldry, Sarshar, & Newton, 2002).

Construing a definitive statement of what qualitative research entails in practice management is challenging as the research topic, theory and methodology are closely interrelated. It is recognised that this approach generates a large volume of complex data, but enables flexibility to select an appropriate method of analysis. This qualitative model of inquiry represents a legitimate mode of practice-based exploration without apology or comparisons to quantitative research, and demonstrates the rigor, difficult, and time-consuming nature of this approach (Creswell, 1998).

There is a consensus that managerial research is expressive and persuasive when qualitative inquiry in undertaken in a natural setting, and whereby the researcher is instrumental in data collection (Bogdan & Biklen, 1992) (Eisner, 1991) (Merriam, 1988). Indeed, qualitative inquiry is often defined by comparing it to quantitative inquiry, suggesting that quantitative researchers work with a few variables and many cases, whereas qualitative researchers rely on many variables and a few cases (Ragan, 1987).

At the initial stage of this inquiry, the researcher considered adapting a qualitative methodology in the form of participatory action research (PAR); a philosophical approach, which enables researching professionals to better understand and solve problems in practice (McKernan, 1988). *If you truly want to understand something, try to change it – Kurt Lewin.* Most change management starts with high resistance, where its strength lies in its focus on generating solutions to practical problems, and its ability to empower practice by engaging with research with consequential development or implementation of design activities. A major strength of PAR is that it allows the researcher to be a committed participant, facilitator and learner in the research process rather than being detached. This philosophy advocates that participants are not subjects of research, but are active contributors that participate in all phases of the research process (Chandler & Torbert, 2003).

Despite being an effective and reputable approach, PAR has its challenges. Participants may struggle to maintain their commitment to the research over time (Gills & Jackson, 2002). Furthermore, and principally due to limited time constraints, the researcher has deemed this approach impractical.

The researcher also considered a grounded theory approach, which identifies problems in practice and how practice manages and improves upon them over time. It involves formulation, testing, and reformulation of propositions by the professional researcher until a theory is developed (Martin & Turner, 1986). This construction of theory through the analysis of data lends itself well to qualitative investigation. However, the researcher has also discarded this theory discovery methodology due to time constraint and participant commitment.

The qualitative research approach to this inquiry is *inductive* in nature, moving from specific observations to broader generalisations and theories, as opposed to *deductive,* which directs generalised observations to specific theory.

3.5 RESEARCH STRATEGY

This managerial inquiry focuses on contextual conditions in practice relevant to the phenomenon under study, whereby case study research is justified (Yin, 2003). Indeed, this inquiry intends to accomplish something greater than an implicit and explicit understanding of practice management. To this end, an *instrumental* case study plays a supportive role by testing the various components of the theoretical framework from triangulated data (Stake, 1995) principally through interviews, and supplemented by case study document analysis and the assessing the researcher's self-reflective journal. The propositions derived from this theory-test produced a *revised* framework (Cavaye, 1996). Moreover, the *multiple unit of analysis* in this case study is the entity that framed what was being analysed by the empirical convergance of people, processes and technology within which the factors of causality and change exist *(Figure 42).*

The researcher brings a structure of reality to this research, principally through the interview method by interacting with practitioners' interpretations of the phenomenon being studied. The final product of this study is a refined interpretation by the researcher of others' views filtered through their own (Merriam, 1998).

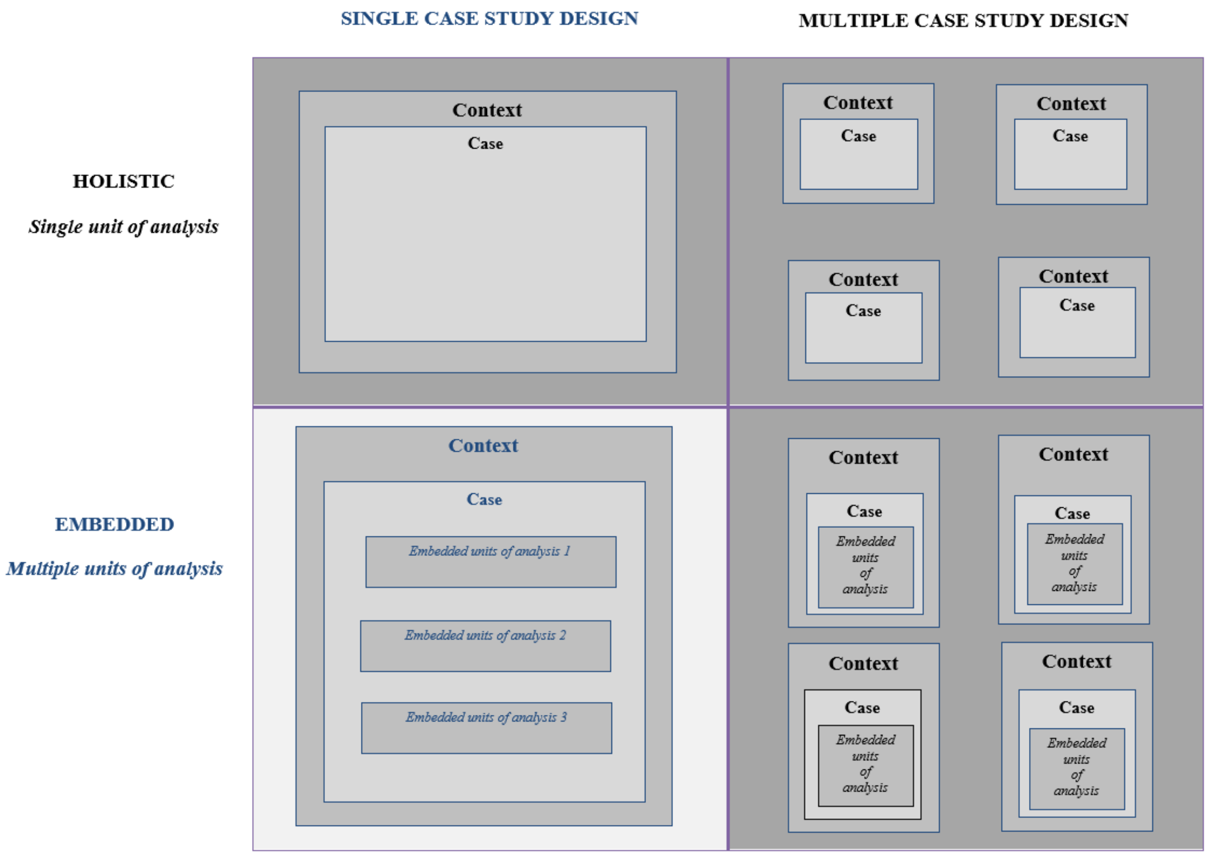

Figure 42 *Design types for case study research* (Yin, 2018)

It is acknowledged that there are limitations in terms of conducting one case study, which may make it difficult to reach a generalising conclusion (Tellis, 1997). However, establishing strong parameters and setting the clear objectives of the research are more critical in case study design than a broader sample size (Yin, 1994). It is also surmised that conducting a qualitative single case study could allow BSE management to judge whether there are real applications in practice based on the findings.

The instrumental case study in this research takes the form of a cross-sectional analysis of a practice-based project; a world-class grandstand building in County Kildare with a construction value of €86M completion June 2019. This project encapsulates the complete lifecycle from briefing to occupation, which was delivered by the researcher, thus providing an excellent insight into BSE practice at both design and construction stages *(Figure 2).* This single case study research is intended to illuminate the practice-based problem identified by the researcher. Notably, this strategy is not typical in BSE practice, but is maximised to the extent of what can be learned about the phenomena (Stake, 1995). The researcher also conducted a pilot study at the early stages of this doctoral programme *(2016-2017)* to inform this research design.

The principal benefit of conducting a pilot study provided the researcher with an opportunity to make adjustments and revisions in the main research, and indeed, uncover ethical as well as other key practical issues (Sampson, 2004). Despite such studies have many useful functions in qualitative inquiry, they have attracted scant attention in research literature (Yujin, 2010).

Furthermore, this research strategy also resonates with that of an ethnography inquiry, where a culture is studied, and the researcher can neither fully remove their own experiences nor be part of the inherent research process This intimates that autoethnography consciously combines elements of ethnography and autobiography, where the researcher actively situates the self within the practice culture being studied (Keefer, 2010).

3.6 TIME HORIZON

The data extrapolated by the interview method was conducive of a *cross-sectional* time horizon during normal working practice environs (Bryman, 2012). This time horizon is not dependent on the specific research approach or methodology used in the inquiry (Saunders, Lewis, & Thornhill, 2007).

3.7 DATA COLLECTION METHODS

The choice of research methods was made in order to collect the most useful data in response to the specific research aim (Davies, 2007). To strengthen the qualitative research design and minimise the limitations of each individual method, triangulated data principally from *interviews*, and supported by *document analysis* and the use of a *self-reflective journal;* the researcher continually recorded their observations from analysing documentation during the design and construction stages of the practice-based case study, which gave self-assurance to the research findings and conclusion.

By not relying on a single method, more confidence to the research is afforded by increased reliability and validity; the weaknesses of one method is compensated by the strengths of the other (Holtzhausen, 2001). The various components of the inherent theoretical framework were tested by data from these three sources.

3.7.1 INTERVIEW METHOD

A great deal of qualitative material comes from talking with people, whether it is through formal interviews or informal conversations (Woods, 2006), by allowing the participants to reflect and consider their responses carefully. The interview remains a popular method of data gathering by researchers in the built environment discipline, principally due to the flexibility afforded. *Interviewing* offered the researcher access to experiences in practice during design and construction stages, which is a empirically fundamental in this inquiry (Reinhartz, 1992). The interview questions were primarily informed from the findings in the literature review, and presented to the participants in the context of the case study project, thus allowing them a reasonable opportunity to answer in their own terms (MacDonald, 2012) *(Appendix 12).*

Structured, open-ended interviews was adopted for this inquiry, which required structured questions facilitating faster interviews that could be more easily analysed and compared (Knight & Ruddock, 2008). This data was used to test various components of the theoretical framework. It is acknowledged that researchers can inadvertently influence the interview result, and thereby, jeopardise the purpose of the research. For this reason, the researcher was an attentive listener who shaped the interview process and the quality of the information obtained therein (Patton, 1990). *Interviewing* offers the researcher access to participants' ideas, thoughts and memories in their own words rather than solely in the words of the researcher (Reinhartz, 1992). Both the researcher and the participants shared and learned throughout the interview process in a reciprocal manner. At the most basic level, interviews are consversations (Kvale, 1996). From highly structured face-to-face questionnaires used in qualitative studies to open-ended interviews that are used to generate insights and concepts, rather than generalise about them. People, in the context of the interview and the participant, are inherently complex, and issues such as completeness, accuracy tact, precision and confidentially were considered carefully (Knight & Ruddock, 2008).

A key feature of the interview form conducted is the nature and relationship between the researcher and participants, who formed a partnership to negotiate highly detailed and valid set of qualitative data. This placed great responsibility on the researcher, who was aware of the many ways in which he could inadvertently influence the interview result, and thereby, potentially jeopardise the purpose of the inquiry. The researcher considered all the data obtained and analysed it with a clear and unbiased mind.

This most common bias can occur when a researcher interprets the data to support their hypothesis. In this instant, the researcher continually re-evaluated the responses, and ensured that pre-existing assumptions were kept at bay. Thus, the researcher stayed objective to minimize bias throughout the entire research process.

3.7.1.1 RATIONALE FOR PARTICIPANT SELECTION

The participant sampling for the case study design is opportunistic and purposeful for maximum variation of professionalism within and closely associated with BSE practice at design and construction stages. A sample of 15-industry professionals from the case study project design team were strategically chosen to participate in the interview process relating to the respective stages of the project lifecycle. The participants had varying degrees of experience in BSE design, programme and cost control, and mechanical and electrical engineering contracting, and were appointed as part of the design team with the researcher on the case study project *(Figures 43 & 44)*. This practice-based case study project included a modern grandstand building in Ireland completed in 2019 with a construction value of €87million *(Image 5).*

There are many practical recommendations regarding the sample size, and suggestively, 12-20 interviews are deemed adequate in this research strategy (Onwuegbuzie & Leech, 2007). Each interview lasted 27-44 minutes. Transcripts were prepared from recordings with the participants' consent, and analysed thereafter *(Appendices 13, 14, 15, 16, 17 & 18).* Each participant was contacted beforehand, and briefed on the nature of the inquiry, but specific detail with regard to the content of the questions was not revealed, so as to capture spontaneous views and opinions, and thereby, minimising response bias.

DISCIPLINE	NUMBER OF PARTICIPANTS	DESIGN STAGE	CONSTRUCTION STAGE
BUILDING SERVICES ENGINEERING	7	*	*
PROGRAMME AND COST CONTROL	3	*	*
MECHANICAL AND ELECTRICAL ENGINEERING CONTRACTOR	5	*	*
TOTAL	**15**		

Figure 43 *Interview sample for instrumental case study*

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT PRACTICE
BUILDING SERVICES ENGINEERING PRACTICE				
1	MEP Engineering Director	Master in Engineering	28	4
2	Mechanical Engineering Lead	Bachelor of Science	12	4
3	Senior Mechanical Engineer	Master in Engineering	8	3
4	Project Mechanical Engineer	Bachelor of Science	5	4
5	Electrical Engineering Lead	Bachelor of Science	16	6
6	Senior Electrical Engineer	Bachelor of Science	12	2
7	Project Electrical Engineer	Bachelor of Science	5	5
PROGRAMME AND COST CONTROL PRACTICE				
8	PCC Practice Lead	Bachelor of Science	28	28
9	Lead Programme & Cost Consultant	Bachelor of Science	25	25
10	Project Programme & Cost Consultant	Master of Science	9	9
MECHANICAL AND ELECTRICAL ENGINEERING CONTRACTOR				
11	MEP Coordinator	Bachelor of Science	25	10
12	Electrical Engineering Contractor Lead	Bachelor of Science	32	20
13	Mechanical Engineering Contractor Lead	Bachelor of Science	15	10
14	Cost Control Manager (Electrical)	Bachelor of Science	9	5
15	Cost Control Manager (Mechanical)	Bachelor of Science	11	7

Figure 44 *Interview participants for instrumental case study*

Image 5 *Practice-based case study project*

3.7.1.2 RATIONALE FOR INTERVIEW QUESTIONS

The interviewing method was adopted as the primary source of data collection. The interview framework comprised of twenty-eight *structured open-ended* questions, which were synthesised from the literature in the context of the three central themes in this managerial research; people, process and technology *(Appendix 12).* Question numbers 1-5 delved into the fundamental principles of BSE practice in terms of its evolution; past and current descriptors, education, practitioner experience outside the design process, design frameworks, financial success, professional grade transition and perceived inefficiencies. Such *general* questions were intended to put each participant at ease (Magnusson & Marecek, 2015).

By delving deeper into the practice *processes*, question numbers 6-12 were framed to explore practitioner experience from the importance of design management and planning, programme time and value management, quality and performance management, safety in design, technical coordination and information and knowledge management BSE practice. Question numbers 13-24 explored the inextricable *people* and technical-social dualism by probing into practitioner experience in practice and academia, knowledge generation, reflective and learning practice, and perceived management strategies. Furthermore, question numbers 25-27 related to the existing and new *technology* in practice.

3.7.2 DOCUMENT ANALYSIS

To enhance the reliability of data collection, design and construction documentation relating to the case study project was reviewed by the researcher to assess how BSE practice fared over time *(Figure 42)*. This systematic procedure entailed appraising and synthesising data from these documents, and interpreting their content to elicit meaning, gain understanding and develop empirical knowledge from both management and technical perspectives (Corbin & Strauss, 2008).

This iterative process by categorical content consideration of *people*, *processes* and *technology* permitted the researcher to conduct alternate testing of various components of the theoretical framework. Indeed, this document analysis also generated questions, which demonstrated how one data collection method can complement another in an interactive manner (Bowen, 2009).

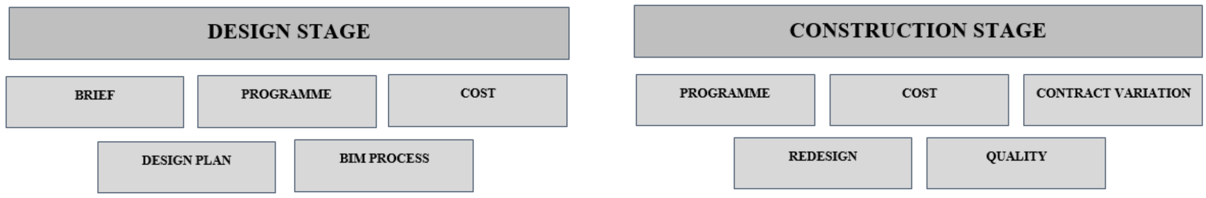

Figure 45 *Document analysis*

3.7.3 SELF-REFLECTIVE JOURNAL

Qualitative research demands a high degree of reflection, where researchers critically examine their role throughout the research process, and how their biases and decisions may affect the data (Ortlipp, 2008). This reflective approach to the research process is now widely accepted in qualitative research (Orange, 2016). This continual critical process of self-reflection allowed the researcher to consider the influence their positionality plays in their research in the context of the inquiry setting, the interview participants, the data collected, and how data is interpreted (Berger, 2015) (Schwandt, 2007).

By association, and in support of triangulated data collection strategy, a self-reflective journal was adopted to document both personal and professional practice assumptions during the delivery of the case study project with the intention of clarifying self-belief systems and subjectivities (Ortlipp, 2008) *(Image 43).* It served to document the methodological decisions made throughout the inquiry, direct the analysis process, document the emergent concepts, and initiate data interpretation (Bazeley, 2007) (Etherington, 2004). The reflective journal writing also allowed the researcher to map their growing and changing understanding of their role as researcher, interviewer, and interpreter of the data generated from the interviews, and to record decisions made and theoretical justification for the decisions (Orange, 2016).

Methodologically, this is an accepted practice from constructivist and interpretivist perspectives (MacNaughton, 2001). This deliberation led the researcher to conclude that the ability to self-reflect on how and what they have researched did improve through engaging continuously in reflection journal writing, although this influence was not manifested to a measurable effect (Lew & Schmidt, 2011).

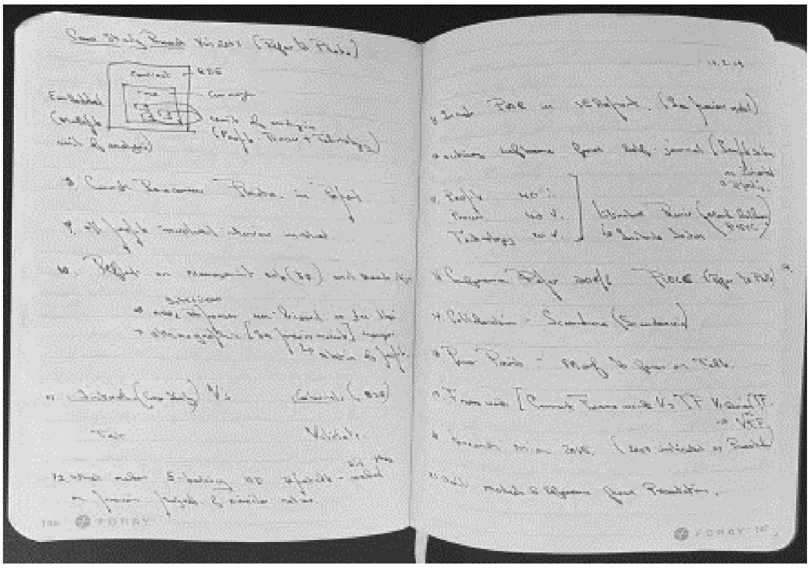

Image 6 *Researcher's self-reflective journal*

3.8 METHOD OF ANALYSIS

The power and flexibility afforded by the interview method comes at a price. Planning and preparation for qualitative research interviews, and later gathering and analysing interview data, were all highly time-consuming activities for the researcher (O'Leary, 2004). After conducting the interviews, the researcher carefully masked the names of the participants, and procured transcripts of the dialogue. Initially, qualitative analysis software (NVivo) was considered as an informed method by reckoning interview references to codes. However, following a number of trial applications, the researcher questioned the accuracy of this software analysis to their research topic. Consequently, the *theory of interpretation* was adapted to examine how statements made by the participants are inter-related to create the bigger-picture (Knight & Ruddock, 2008). This manual categorical data analysis enabled the researcher with greater control of the data, whilst testing the theoretical framework in a pragmatic manner.

3.8.1 QUALITATIVE DATA ANALYSIS

The analysis of qualitative data is arduous as it is fundamentally neither a mechanical nor technical exercise. In fact, it is a dynamic, intuitive and creative process of inductive reasoning and theorising, which underpins this research design (Basit, 2003) *(Figure 4).* Throughout analysis, the researcher gained a deeper understanding of what they have researched and to continually refine their interpretations, thus drawing on their professional experience with settings in practice and documents to interpret their data (Taylor & Bogdan, 1998).

The key objective in analysing this qualitative data is to determine the categories, relationships and assumptions that inform the interview participants' view of the research topic (McCracken, 1988). It is argued that this analysis of qualitative data is the most demanding and least examined aspect of the qualitative research process (Miles, 1979). There is no short cut, and the researcher allowed sufficient time and energy to analysis data, which was continued throughout the research process as opposed to a separate self-contained phase (Delmount, 1992). Raw data is undoubtedly interesting to read. However, it does not help the researcher to understand the *research* under scrutiny, and the way they view it, unless such data have been systematically analysed to illuminate the practice problem.

Coding and categorising the interview data had an important role in this analysis, which involved subdividing the data as well as assigning categories of *people*, *processes* and *technology (Figure 43)*. Such categories and codes were labelled for allocating units of meaning to the descriptive or inferential information compiled during this inquiry (Dey, 1993).

The role of *coding* highlighted relevant phenomena, collating instances of those phenomena, and analysing those phenomena to ascertain *themes and differences*. Assessing the *categories'* data produced a revised framework. This scheme aided the researcher to ask further questions to compare initial findings with the subsequent *validation* qualitative data, and make a hierarchical order of them (Seidel & Kelle, 1995) (Miles & Huberman, 1994).

3.8.2 DATA DISTILLATION

The term *data distillation,* a descriptor of the outcome of this qualitative analysis, implies that the body of collected data became smaller and manageable during the analysis process. This was the result of interpretation and well-planned research (Tesch, 1990). The integral process of establishing categories was a very close, intense conversation between a researcher and the data that had positive implications for the inherent research method, descriptive reporting and theory building (Ely, Anzul, Friedman, Garner, & Steinmetz, 1991). On devising the three categories, the researcher made decisions about how to organise the data, which were useful for the analysis, and took cognisance in accounting how each category *fitted* into the wider context (Dey, 1993). Subsequently, codes were adapted as links between the data and the theoretical framework, which enabled the researcher to develop an informed revised management framework (Coffey & Atkinson, 1996) *(Figure 47).*

Coding and analysis are not synonymous. This qualitative data analysis was not a discrete procedure carried out at the final stage of the research process; it was an all-encompassing activity that continued throughout the inquiry. From the outset, the researcher reflected on how to make sense of codes, categories and themes that could be used to explain the phenomena. The researcher chose to code the data manually, as it is believed that no amount of electronic analytic work would produce new theoretical insights without the application of disciplinary knowledge and creative imagination (Coffey & Atkinson, 1996). The creation of provisional codes prior to the data collection, which were extrapolated from the literature review, afforded a list of problem areas that the researcher brought to this inquiry (Miles & Huberman, 1994) *(Figures 46).* Qualitative researchers believe that only qualitative data respect the complexity, subtlety and detail of participants' transactions. This research analysis was conducted in two phases.

Firstly, the researcher listened to the interview recordings, transcribed the case study interviews *(Appendices 13, 14 & 15)*, read the transcripts a number of times, summarised the transcripts and composed relevant matrices under each category, coded statements, linked themes, selectedquotations, and ultimately, generated theory grounded in the data, thus wrote it up in a coherent fashion *(Appendices 16, 17 & 18).* The data permitted instantaneous inter-interviewee and intra-interviewee comparisons and contrasts, which informed a revised framework *(Figure 54).* A further summary of the preliminary findings from the data analysis by converging people, processes and technology in BSE practice is presented in *Figures 49, 50, 51, 52, & 53*, respectively.

The second-phase *validation* interviews were managed and interpreted in the same way as the first-phase *(Appendices 19, 20 & 21).* From the collective matrices, a number of themes were identified, and were then found to be linked with one another. The interview transcripts, summaries and the matrices were studied again, which is *presented in Figures 54, 55 and 56, respectively.* The above data analysis contributed to the development of the *final* management framework *(Figure 57).*

A spider diagram was also produced at this stage to make sense of the links between the themes. At this point, the transcripts were perused one more time. Illuminative quotations were emphasised *(italic text)* and coded using the three categories identified. A number of these quotations were chosen to be used in the *Findings and Discussion* section of this thesis.

The emergent themes were contemplated again, and these three categories were, again, found to be connected with one another and were further condensed, culminating into a decisive theme. The analyses facilitated the generation of theory grounded in the data.

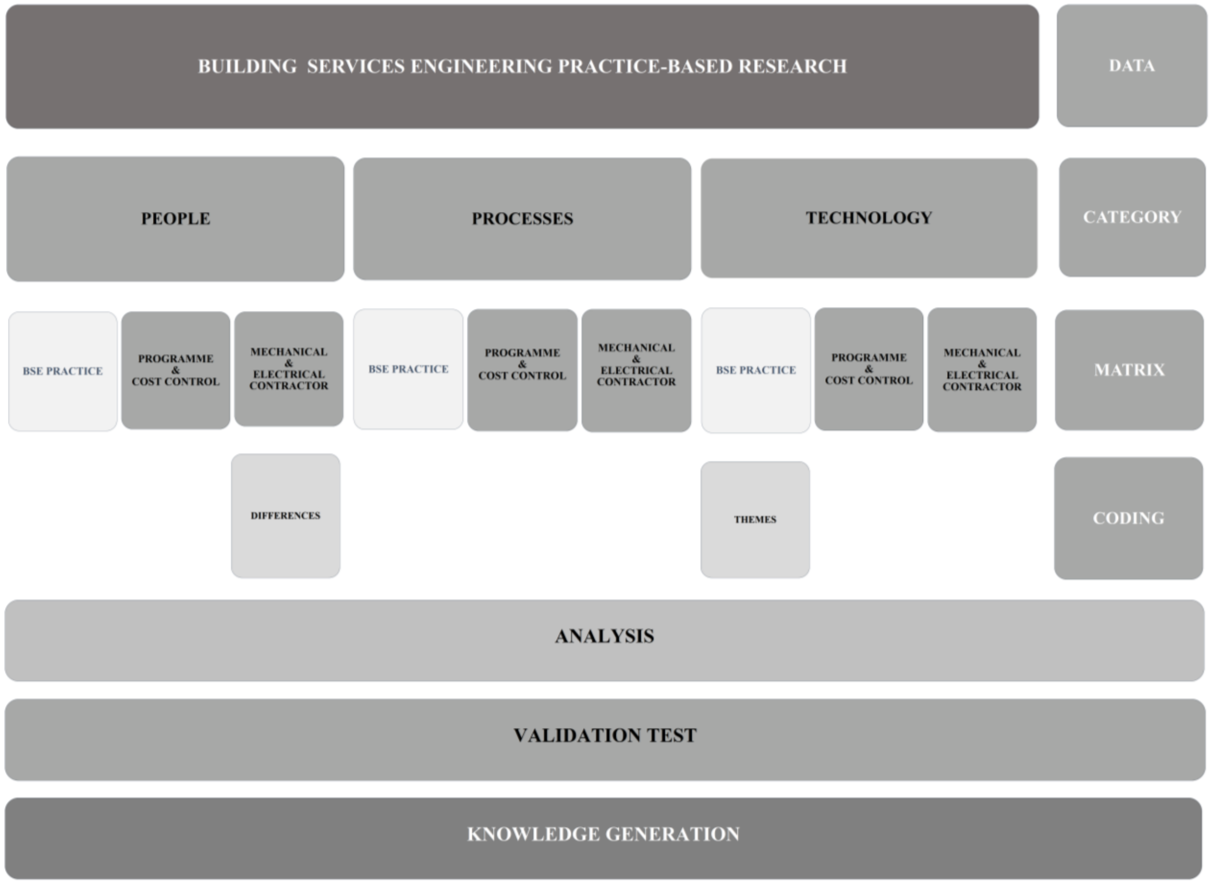

Figure 46 *Data distillation in qualitative research*

Researchers accustomed to quantitative research are tempted to quantify qualitative data to elucidate views. However, design practice phenomena cannot be explained numerically. To this association, the researcher has focused on the quality and richness of the research to their situation in practice. Whilst it may be interesting to know *how many* practitioners feel positively or negatively about the problem, it is not the intention of this qualitative inquiry. The idea is to ascertain *what* they feel, and *why* they feel that way, which also incorporates *who* feels in a particular manner, and *where*, *when* and *how*; this scrutiny cannot be carried out by using numbers, percentages and statistics (Basit, 2003). Qualitative data are textual, non-numerical and unstructured. Coding had a crucial role in this analyses to organise and make sense of them. The researcher discussed coding in the context of data distillation, which permitted him to communicate and connect with the data to facilitate the comprehension of the emerging phenomena (Basit, 2003).

As the researcher progressed with categorising, their decisions became more confident and more consistent as categories are clarified, encountering fewer surprises and anomalies within the data, thus improving the efficiency with which they synthesised the data (Dey, 1993). The final analysis was an intense and prolonged period of deliberation, which required considerable expertise on the part of the researcher (Basit, 2003).

3.8.3 DATA SATURATION

Failure to reach data saturation has an impact on the quality of the research and impedes validity. Essentially, this point of the research was attained when there was enough data to replicate the inquiry, whereby the ability to obtain additional new data was reached, and when further coding was no longer feasible (Fusch & Ness , 2015). A qualitative research design inquiry may come up against the dilemma of data saturation when interviewing study participants, most notably, how many interviews are enough to reach data saturation (O'Reilly & Parker, 2012) (Guest, Bunce, & Johnson, 2006). The field of data saturation is a neglected one as its concept is arduous to define (Fusch & Ness , 2015).

The use of well-defined interview questions in this case study research design assisted the researcher in the quest for data saturation despite being no universal method to reach this status (Amerson, 2011). The researcher agrees with its general principles and concepts, whereby new data, new themes, new coding, and ability to replicate the study is no longer attainable (Dibley, 2011). It was prudent to view data in terms of *rich* and *thick*, where rich is quality and thick is quantity (Burmeister & Aitken, 2012) (Guest, Bunce, & Johnson, 2006). Researchers cannot assume that data saturation is reached when resources are exhausted, but about the depth of the data (Burmeister & Aitken, 2012). If the researcher has reached the point of no new data, they have reached the point of no new themes, and therefore, they have reached data saturation (Fusch & Ness , 2015).

It is affirmed that the number of interviews required for a qualitative inquiry to reach data saturation is not quantifiable. The researcher takes what they can get (Bernard, 2012). Moreover, this research employed structured open-ended interview questions, where participants were presented with identical questions to achieve data saturation. Otherwise, this research analysis would be a constantly moving target (Guest, Bunce, & Johnson, 2006).

To further enhance data saturation, the researcher conducted validation interviews with participants outside their practice (Rubin & Rubin, 2012). This research design was applied with caution as many practices vary in their approach to managing the design process, and therefore, their responses could overshadow the case study data, whether intentionally or inadvertently (Bernard, 2012). This method drives research through openness, which is about receiving multiple perspectives about the meaning of truth in situations, where the researcher cannot be separated from the phenomenon (Fusch & Ness , 2015).

3.8.4 DATA SATURATION AND THE RESEARCHER

The role of the researcher is an important part of this inquiry, particularly in addressing data saturation. The view through the researcher's professional lens assumes no bias in their data collection, thus they were cautionary in terms of not recognising when the data is saturated.

However, interview participants' and researchers' bias is evident in all practice-based research, both intentionally and unintentionally (Fields & Kafai, 2009). In this inquiry, the researcher is the data collection instrument and cannot separate themselves wholly from the research, which instigates concern (Jackson, 1990). In essence, the researcher operated between the practice world of the participants and the world of their own perspective world, whilst engaging in this research (Denzin, 2009). Henceforth, it was imperative that the interpretation of the phenomena represented that of participants and not of the researcher in order for the data to be saturated (Holloway, Shipway, & Brown, 2010).

Analysing the perspective of others was one of the most difficult dilemmas that faced the researcher, where they recognised their view of practice, and discerned the presence of a professional lens, thus interpreting the reflections of others in a non-biased manner (Fields & Kafai, 2009). Despite the researcher's experiential background contained biases, values, and ideologies that could potentially affect when the data was saturated, the researcher recognised their role in the inquiry and mitigated any concerns during data collection (Chenail, 2011) (Bernard, 2012).

3.8.5 DATA TRIANGULATION

The researcher was cognisant of the importance of data triangulation from the outset of the data analysis, which is perceived to contribute to the inherent data saturation, thus enhancing the reliability of the research outcome (Denzin, 2009) (Stavros & Westberg, 2009). This process involved adapting multiple external methods to collect data, including analyses of both the case study documentation and the researcher's self-reflective journal to support the interview method (Denzin, 2009). To enhance objectivity, truth, and validity, this methodological triangulation permitted data correlation from these multiple data collection methods (Fusch & Ness , 2015) (Holloway, Shipway, & Brown, 2010).

There is a direct link between data triangulation and data saturation, whereby the former ensures the latter. This unique triangulation approach permits exploration at different perspectives of the same phenomenon; it is a method by which the validity of the case study results are strengthened. The researcher was mindful that triangulation of data could yield a contradictory outcome. This was cautiously addressed by making absolute sense of the outcome by focusing on the *richness* of the data extrapolated (O'Reilly & Parker, 2012). Moreover, the researcher considered triangulation as *crystal refraction* to extrapolate the meaning inherent in the data. Researchers do not necessarily triangulate, but rather they crystallise by recognising that there are multiple angles to approach a theory (Richardson & Adams, 2008).

However, it is important to emphasise that *rich* and *thick* data outcomes may not represent data saturation, particularly when it comes to *autoethnography*, where the researcher is an insider member of the group being studied in contrast to the traditional role played by researchers on the peripheral of a group (Wolcott, 2004). Despite ethnography being a strategy of inquiry in culturist research, there are similarities in this research insofar as the researcher can never fully remove their experiences from the research process. This approach respects that autoethnography consciously combines elements of ethnography and autobiography, and is a genre of research that displays multiple layers of consciousness. The researcher actively situates the self within the culture being studied, and is connected to the participants in the researcher's experiences (Keefer, 2010).

The researcher has a keen interest in this form of research as it has educational implications for establishing, critically understanding, and developing their identity as a manager, with elements of learning and practice transformation within it (Mezirow, 2000).

3.9 FRAMEWORK VALIDATION

As part of the research design, the interview method was also selected as a key validation tool *(Figure 47).* The validity of the *revised* framework *(Figure 54)* was tested by conducting structured, open-ended interviews with external participanst. Similarly, this researcher gave careful consideration to the selection of interview participants, thus selecting a sample of five seasoned professionals from leading BSE practices in Ireland *(Figure 48).*

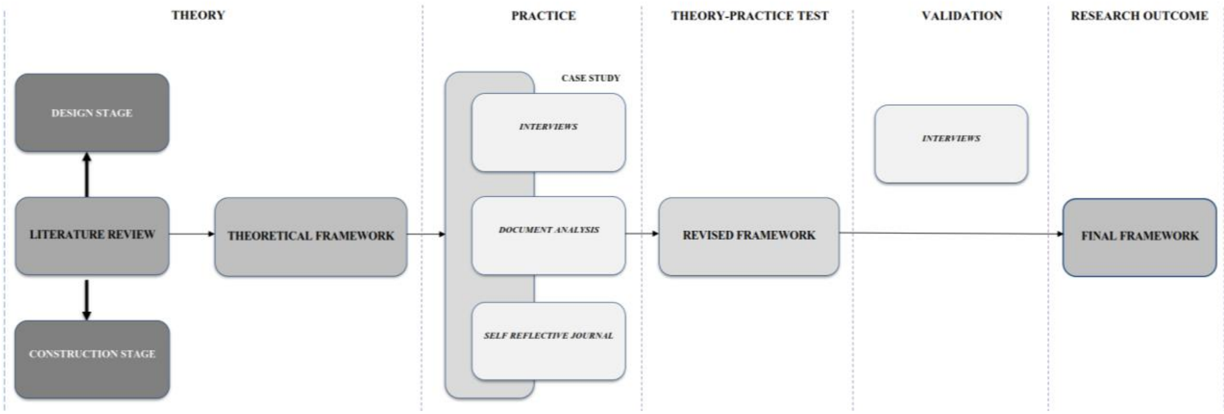

Figure 47 *Research process model*

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT ENGINEERING PRACTICE
BUILDING SERVICES ENGINEERING PRACTICE				
1	Managing Director	*Master of Science*	28	28
2	Managing Director	*Bachelor of Science*	25	15
3	Technical Director	*Master of Science*	17	5
4	Technical Director	*Bachelor of Science*	19	5
5	Technical Director	*Master of Science*	14	2

Figure 48 *Interview participants in validation study*

3.10 ETHICS

Ethical problems exist in academic research, most notably, misconduct in fabrication and falsification in reporting research, and questionable research practices, such as keeping poor research records or permitting honorary authorship, and accidently identifying people who may expect to remain anonymous.

As the field of *engineering* in the built environment constitutes human endeavours, it is unlikely that an entire fail-safe system can be designed to impede such forms of misconduct *(Swazey, Anderson, & Louis, 1993)*.

Consequently, practice-based doctoral research in the built environment must be challenged on both technical and ethical grounds, taking cognisance of its complex interrelationship with potential commercially viable constructs. The beneficiary from such research is invariably questionable, and haphazardly, technical and ethical inquiries cannot be fully detached in this instant, which could lead to intractable problems of academia *(Eraut, 1985).*

This inquiry mandated ethical approval as the research design involved human subjects working in their professional environment. As research findings could potentially be offensive, and may bring practice into disrepute, an application was submitted for approval to the School of the Built Environment Research Ethics Committee *(Appendix 2).* Respect for persons commanded interview participants to enter the research process voluntarily, and with good information about the research aim *(Appendices 7, 8 & 9).* The selection of research participants was explicitly justified explicit for reasons directly related to the research problem being investigated (Levine, 1979).

CHAPTER 4 DATA ANALYSIS AND DISCUSSION

4.1 INTRODUCTION

This chapter is structured according to the theoretical framework *(Figure 39),* where sections and subsections were created to present and describe each portion of the results systematically and consistently. The quotes used to substantiate the researcher's claims from the empirical analysis was presented in ***italics*** to differentiate them from their own words. As a general rule of thumb, the researcher presented at least two pieces of evidence per claim, which were linked directly to the data. In addition to including quotes, the researcher linked their claims to the data by using appendices, which was reference throughout the text.

4.2 DATA PRESENTATION

The interview method generated insights and concepts, and expanded the researcher's understanding of management and practitioner experience (Knight & Ruddock, 2008). However, the over-reliance on interviewing can often attract criticism in terms of potential biased on practical and pragmatic considerations, such as the truthfulness of the participants and the differences between what they say and what they actually do (Hammersley & Gomme, 2005). This critique could perceive the interview participants as being more focused on self-presentation and the persuasion to the interviewer, rather than on presenting real facts about their experience (Dainty, 2008). To alleviate such demerit in this inquiry, the interview participants were counselled by the researcher to respond in an honest and professional manner *(Refer to Appendix 8: Interview participant information sheet).* The structured, open-ended interview design also allowed the researcher to be good listener rather than a speaker during the interview process (Creswell, 1998).

Coding and categorising the interview data had an important role in this analysis, which involved subdividing the data as well as assigning categories of people, processes and technology *(Figure 46)*. Such categories and codes were labelled for allocating units of meaning to the descriptive or inferential information compiled during this inquiry. The role of coding highlighted relevant phenomena, collating instances of those phenomena, and analysing those phenomena to ascertain themes and differences.

Assessing the categories' data produced a revised framework. This scheme aided the researcher to ask further questions to compare initial findings with the subsequent validation qualitative data, and make a hierarchical order of them.

4.3 THEORETICAL FRAMEWORK TEST

The following analysis tests the various components of the theoretical *BSE* management framework *(Figure 39)* principally by the interview method, and supplemented by case study documentation and the researcher's self-reflective journal. A summary of the preliminary findings from the data analysis by converging people, processes and technology in BSE practice is presented in *Figures 49, 50, 51, 52, & 53*, respectively. In addition, all participant interview transcripts and initial analysis are contained in *Appendices 20 and 21*, respectively.

4.3.1 PEOPLE

4.3.1.1 PRACTICE AND ACADEMIA

The postgraduate experience of each participant ranged from 5 to 32-years. All participants agreed that the Irish educational system does not adequately prepare graduates for engineering practice. Albeit technical theory underpins successful design, it is concluded that the lack of practical experience in the BSE curriculum is a significant weakness, thus viewing graduates as living in a *2-d world*. Most worryingly, it is believed that graduates are unaware of the *real* implication from adjusting detailed design, and its inherent impact on other design disciplines, most notably, in architectural and structural engineering constructs.

What was once deemed the province of a craftsman in the mid-twentieth century now demands the services of a body of highly educated and specialist trained professional engineers categorised as academic inflation by the evolution of *craftsperson to professional.* However, it is surmised that academia alone does not form a solid foundation for BSE graduates. BSE participants believe that there is a *narrow-mindedness* amongst graduates, initiated by higher education institutes, that focus on teaching undergraduates how to think and conduct processes, but without a holistic design approach.

Bridging the gap between academia and practice is imperative to successful design, whereby practical experience in a BSE practice during academia would enhance graduates' initial years. Theoretical design is prioritised at higher education institutes with limited taught-management skills, which is the key for career progression. People drive practice as opposed to their qualifications.

Moreover, apprenticeships in conjunction with academia is believed to be an excellent platform to prepare graduates for practice. However, the real learning curve for new graduates relates to client and multidisciplinary engagement and site experience through attendance at design and project team meetings. This practical endeavour by employers taking-on graduates in practice during academia would enhance graduate experience, thus facilitating a solid background for construction professionalism.

Programme and Cost Control participants traditionally perceive BSE management with a *craftsman's background*, where practical experience is followed by academia. This is quite the opposite in practice today, thus concurring with the view that academia prepares graduates to an extent, but lacks hands-on practical experience. Such trade experience at undergraduate level would enhance practitioner knowledge, where academia would be an important *stepping-stone* into the professional world of design. However, graduates must possess an interest in their future career, and show some desire to learn from taught programmes coupled with *work-placement for real exposure* to office dynamics, teamworking and management.

Mechanical and Electrical Contractor participants concur in their belief that the Irish education system does not adequately prepare graduates for engineering practice from a practical perspective. Notwithstanding that technical theory and calculations at undergraduate level underpins successful design, it is suggested by the Mechanical and Electrical Contractor participants that 80% academia and 20% practical placement schemes could improve the graduate-practice dichotomy. There is also a sense that higher education institutes are more focused on rolling out new technology software to undergraduates rather than being led by current digital constructs in practice.

The invisible aspects of engineering practice have evolved over time to control all the uncertainties and unpredictable elements of management that arise because engineering is a social system (Trevelyan, 2009).

All interview participants concur that the importance of promoting *equality* in practice helps develop and sustain good working relationships, thus sustaining a high-performance team. Successful BSE management entity achieves client satisfaction, provides technically sound professional services, whilst maintaining a supportive and rewarding working environment for their practitioners. BSE participants advocate that *people respect and support each other* is imperative in practice, which sponsor their belief that a *thrown-under-a-bus scenario* should never arise in successful practice. A *harmonious* content environment promotes an efficient design process, where multi- and multidisciplinary *technical collaborate*, *comfortable communication* and *trust* is evoked. Having the *right people* with the right technical know-how enhances this process. Quality assurance and quality control procedures are adhered through the *art of delegation with trust*. This *personable* combination of technical and practical-oriented practice yields a well-balanced team under solid management. A *strong team spirit* with a supportive working environment by *total transparency* of formal and informal communication enables efficient design productivity and project delivery.

Programme and Cost Control participants believe that a *creative* and *supportive* network in practice undoubtedly delivers a high-quality professional service. It is encouraged that *upskilling management and their practitioners in state-of-the-art technology* not only promotes career progression and good relationships in practice, but has the capability to overcome issues such as design time constraints, lack of knowledge and the lack of resources to complete tasks competently. Mechanical and Electrical Contractor participants perceive a healthy design practice led by respectful management offered technically sound professional services by bringing *people of the same mindset* to interact to produce good quality design, as opposed to relying heavily on Mechanical and Electrical Contractors and vendors to provide elements of design at construction stage. However, this pragmatic preposition of BSE practice being hands-on, practical, and on-the-ground solving problems, Mechanical and Electrical Contractor participants are wholly cognisant that competitive low design fees can somewhat restrict this endeavour.

The common juxiposition of people having different opinions on the same end goal can often lead to a stressful working environment. Mechanical and Electrical Contractor participants advocate that an *open communicative team culture* with *honesty and hard-work* encourages an *enjoyable work environment with a positive mental attitude* to deliver a coherent and improved design process.

4.3.1.2 KNOWLEDGE GENERATION

Engineering is increasingly being recognised as a technical and social process. Indeed, it has been articulated that its management has a conceptual mind, whereas contractors have a concrete mind (Sugumaran & Lavanya, 2013). It is argued thereon that practitioners design conceptually for concrete practicality at installation stage. This phenomenon alone suggests dissonance between design and construction professionals, henceforth, the need to improve the technical-social dualism to generate knowledge in practice.

BSE management often devise either *over-simplistic* or *unnecessary over-complicated* views to a design solution, whereby contractors tend to steer solutions from a more practical stream. Bridging this gap would produce better solutions. Moreover, management-client relationship is often complex, where clients' technical knowledge varies from project to project, and where management technical savviness may conflict with that of the client, thus the perception of different outcomes. However, this contention can be managed by a clear mutual understanding of the end-goal. BSE practice is confident that professional institutes lessen this inherent technical and social gap.

The design process is deemed *intangible* from a BSE practice perspective, whereas design is perceived as *tangible* from an Mechanical and Electrical Contractor's perspective. BIM adoption is distinguished to alleviate this gap of *conceptualisation* and *concretisation*. The *forced adoption* of a design-oriented BIM model by Mechanical and Electrical Contractor's has the potential to develop their design mindset. However, BSE practice needs to be wholly cognisant of design and installability during the design process. Mechanical and Electrical Contractor participants believe that they tend to take a *black-and-white* and *right-or-wrong* approach at construction stage, which unbeknownst to them initiates dysfunction in BSE practice. Traditionally, BSE practice is design focused, whereas Mechanical and Electrical Contractors participants view their profession as *financially driven*, with a keen attention drawn to design changes that warrant additional costs.

Interestingly, Programme and Cost Control participants perceive BSE practice and Mechanical and Electrical Contractors *huddling-up to work out the practical aspect* of installability to collaboratively understand the design intent. Programme and Cost Control participants expressed concern that BSE management is *not wholly mindful* of the *road to installation*.

Mechanical and Electrical Contractor participants trust that professionals' true project success is achieved by investing time in peer mentorship. The art of *confidence-building* by BSE management may be established by developing a preliminary construction model at design stage by early engagement with the Mechanical and Electrical Contractors. Moreover, Mechanical and Electrical Contractor participants deduce that off- and on-site separation between BSE management and Mechanical and Electrical Contractors often leads to miscommunication and delays in problem-solving, thus the need for an improved collaboration strategy to expedite the validity of both commercial and technical constructs.

There is limited or no formal training associated with traversing professional grades in practice, and by association, management knowledge. The design-management transition is often perceived as a *default career progression*; a role adapted through a *trial-and-error* process. BSE participants envisage that management comprises of creative and technical excellence, and can only evolve from relevant *design experience* and technical *know-how*. This contradicts the literature, which suggest that this transition can only work if practitioner take an holistic approach at applying what are traditionally separate disciplines (Armstrong, 2001). There is a belief in BSE practice that management lack an understanding of the design process, and by implication, lack an appreciation for other disciplines' design, which ultimately, leads to poor technical coordination.

The absence of a formal transition process from practitioner to management is clearly evident. It is suggested that higher education institutes' curriculum could introduce management modules, where both project management and technical knowledge are deemed fundamental to bridging this gap. Generally, BSE management commands *hands-on-deck quality* with excellent communication skills, but lack a self-management strategy. BSE participants believe that tacit and explicit knowledge is transferrable to future management, which can mitigate against this *self-learning trial-and-error* shift.

Programme and Cost Control participants assume that practitioners *naturally* ascend to a managerial role, thus perceiving management as being conscious of self-discipline with career progression in mind, which is permitted thereon by training and mentorship from current peers. *Experiential learning* and *learning-by-example* are viewed as key management enablers. The preposition to take on more responsibility through practice promotion requires undue upskilling. Mechanical and Electrical Contractor participants concur with both BSE participants and Programme and Cost Control participants that formal training for this transition is limited.

As pivotal role in BSE practice, Programme and Cost Control participants believe that a BSE management is not something one can train directly, but rather it comes with experience, and commands inordinate technical know-how with a *teased-out* soft dimension.

4.3.1.3 REFLECTIVE PRACTICE

The primacy of self-reflection in scholarly practice is key to management success (Schon, 1983). BSE participants view reflective practice as mindful adaptation of *lessons-learned* on past projects to future design. All participants admit that there is no specific prerequisite during the design process to *formally* record reflection. Management often provide constructive *criticism to* practitioners in terms of their design approach, and view reflective practice as key to improving future practice. The literature suggests that management actively try to avoid self-reflection, mainly because it might harm their feelings of competence and self-efficacy. In fact, realising one's own failure can be quite detrimental to one's self efficacy. However, the process of reflection in engineering practice is often inspired by discrepancies in existing knowledge, skills and people's attitudes.

Generally, BSE participants believe that reflection in practice is imperative. Notwithstanding being occasionally portrayed by default as *self-criticism,* reflecting on their design to engage in a process of continuous learning, could harmonise the art of learning in-action and on-action. However, there is often a *smack-of-arrogance* amongst management when it is suggested that design cannot be improved by reflective practice alone, but also by learning from experience.

Programme and Cost Control participants concur that reflection attributes to self-development and professional competence, but advocate that the avoidance of a *copy-and-paste design approach* minimizes inaccurate design.
Mechanical and Electrical Contractor participants advocate *nobody knows everything* and that *everybody learns from each other,* highlighting that reflective practice is a *fundamental ingredient* in design, but expressed their concern that time constraints do not always permit its progression.

BSE participants acknowledge working in silos, whilst being *cognisant* of the critical interface necessities between other discipline designs, and argue that this interface is not clearly advocated by management at design stage. It is surmised that there is a dependence on *good* *contactors* at construction stage to rectify the design shortcomings, thus suggesting that improvements in multidisciplinary team coordination at design stage could potentially reduce *implications* during installation. Moreover, dissonance between designs in an multidisciplinary team is often *brushed-under-the-carpet* at design stage, where it is generated through the lack of management responsibility for the overall project delivery.

Interestingly, BSE participants believe that there is a misconception that a multidisciplinary practice is more collaborative, whilst in fact, there is potentially greater collaboration in non-multidisciplinary practices. The notion of *leaving-design shortcomings until a later date* is often forgotten, thereby leading to a snowball effect at construction stage. Various levels of technical coordination between disciplines by the lack of reflection can lead to dissonance, particularly whilst adopting the BIM process, whereby the ability to communicate technical intent to other disciplines can be complex. In the presence of *good* management, practitioners tend to feel more accountable for their design. *Dissonance-by-default* is instigated by time constraints and technical complexity.

Programme and Cost Control participants trust that close collaboration in Irish design teams is evident. They understand that the resolution to shortcomings are generally resolved prior to major problems being developed. However, *building a strong relationship* with other team disciplines is imperative to a successful project. It is surmised that BSE practitioners often *hid behind technology*, whilst attempting to resolve issues. This phenomenon gives rise to a relaxed design approach in a single multidisciplinary practice, where subconscious complacency in standards compared to partnering with external disciplines. Mechanical and Electrical Contractors participants accept that BSE practitioners work in silos albeit cognisant of design interface requirement. Consequently, Mechanical and Electrical Contractors participants also perceive that BSE practice depend on *good contactors* to rectify any design shortcomings in an *inform* manner.

Such disparity generally instigates additional site visits. Similarly, Mechanical and Electrical Contractors participants trust that a single multidisciplinary practice design is fully coordinated, but intimate that this is not always the case unless effective management is instilled. *People by nature focus on their tasks, thus tend to overlook the bigger picture.* Mechanical and Electrical Contractors participants advocate that management need to focus more on installability during the design process, as opposed prioritising client unrealistic expectations.

4.3.1.4 LEARNING IN PRACTICE

A learning practice is skilled at creating, acquiring, and interpreting, transferring and retaining knowledge, thus instilling practice learning at a rate that provides a sustainable professional advantage. The act of learning in a professional practice is directly related to how management can stimulate learning. Management is cognisant of the so-called *half-life* of knowledge in engineering practice. Albeit most managers are normally keen to evade, many do not share this vested interest, highlighting that *you can take the horse to water, but you can't make them drink.*

BSE participants also disclose that *insufficient time for adequate formal training* is directly related to programme demands. This is seen as a major hurdle to learning in practice, particularly when there is an aspiration by management to adopt new digital design technologies. Such time constraints limit managerial research to test the feasibility and accuracy of these predictive machineries. The literature on this subject does not support managerial experience in the *real* world, where practitioners are often unable to meet learning targets through a combination of formal and informal training programs, and consequently, resort to informal training programs.

BSE participants believe that training and mentoring to a qualitative level makes them feel valued. The complete transfer of knowledge from management to practitioner, whereby *the mentored needs to know what the mentor knows* by equipping them for successful project delivery. It is observed that large multidisciplinary practices have an advantage over small single disciplinary practices by offering practitioners global reach, which facilitates the dissemination of specialisms' knowledge. *Learning-by-collaboration* rather than *learning-by-trial and error* is perceived as a priority in practice.

The modern BSE design philosophy is often enhanced by continuous professional development seminars and workshops, which are generally hosted by industry professionals and professional institutes. However, this formal training is also challenging due to project demands. Management often advocate that practitioners learn at their discretion although formal training is preferred with trainer accountability. Caution is raised where informal training may instigate miscommunication and misguidance. Thus far, there is a succinct correlation between project demands and the hindrance to formal learning.

Programme and Cost Control believe that recruiting the right people with the right skillset is fundamental to BSE practice, and concur that a large-scale practice has the capacity to invest and provide *cutting-edge* training to practitioners. However, they advocate that is the responsibility of management to facilitate practitioner diverse training in both technical and business practice acumen in conjunction with professional institutes.

Similarly, Mechanical and Electrical Contractors express their concern that insufficient time is available for adequate formal training. Although an ongoing aspiration to implement new digital design technologies, time constraints limit the research required to test the feasibility of such developments. They advocate that a well-regulated formal training programme by management, whereby practitioners would target remuneration packages and recognition, thus instilling a *thriving* learning environment. Furthermore, there is emphasis to attribute *competent assured mentors* in achieving practitioner chartership status by knowledge sharing, thereby suggesting that practitioners often learn-by-example.

4.3.1.5 MANAGEMENT IN PRACTICE

The difficulty in designing complex engineering projects does not arise from technical complexity, but from managerial complexity, necessary to manage the interactions between the different disciplines, thus imposing additional challenges on the design process (Yassine, Falkenburg, & Chelst, 1999). BSE participants believe that design management needs to be effective from the project outset and continued through all project stages. *Accurate practitioner direction* with clear *decisions* made by management at design stage has a direct correlation to the success of subsequent stages. *Inaccurate design workflow* in practice compromises design quality and programme at construction stage. *Poor delegation from management* to practitioner coupled *with inadequate communication* of the design brief, and unrealistic deadlines conveyed by management at design stage leads to inferior design.

Ineffective management results in extended design timescales and the production of poor-quality tender documentation. Any unresolved design issues must be resolved at some point for the MEP installation to be successful. The cost of design change at installation stage is a multiple when compared to resolution at design stage. However, BSE participants perceive that inefficiencies at design stage are *only realised at construction stage* instigated by the lack of multidisciplinary peer design review.

More worryingly, design development is perceived as a *rectification tool* during installation stage. Practitioners believe that this pattern of thought is due to *practitioner inexperience*, *lack of mentorship*, *lack of appreciation of site constraints*, with an *onus on contractors* to resolve or *fill-in-the-gap* on site, and they believe that *front-loading* the design process would improve practice by embracing a *pure-design*, *pure-thinking* approach. There is a consensus that *reluctance by management* to request additional time to complete a thorough design is inherent in practice.

Programme and Cost Control participants concur that incomplete design at tender stage initiates programme and cost impact at construction stage, but stipulate that this is *dependant* on public or private sector projects, whereby the public sector clients demand comprehensive design in adherence to capital framework guidelines, who in theory, demand adequate programme to produce accurate tender documentation for costing. Conversely, private sector clients demand tender documentation to contain provisional sums for incomplete system design, which leads to technical coordination issues at construction stage. Interestingly, Programme and Cost Control participants believe that poor design performance is instigated from both *the client and BSE management* sides, where their adherence to a lesson-learned adaptation from similar type projects could avoid future mistakes to improve practice.

Mechanical and Electrical Contractor participants conceive inferior BSE design is only a result of *poor technical coordination* as opposed to poor design, which incurs significant programme delays and costs at construction stage, not only affecting the MEP installation, but also traversing to other discipline trades. This phenomenon infers that such deficiencies lead to *battle* and tension between disciplines. Mechanical and Electrical Contractor participants also believe that multidisciplinary design teams are generally *under pressure* to complete tender design packages leading to *limited technical coordination* that *generates costly problems* at construction stage, which could be mitigated by *early contractor involvement* at design stage to ascertain accurate installability.

Management is not about titles, positions or flowcharts, it is about one manager influencing another (Maxwell, 2016). Design practice that excel at design, grow revenue returns at nearly twice the rate of their industry peers, which questions the proactiveness of managers (Dalrymple, Pickover, & Sheppard, 2020). BSE participants characterise an engineering manager as a *highly technically competent, inspirational, approachable to discuss technical queries, and an advocate of a non-blame attitude and culture to practice.*

However, participants elaborate that managers must also *understand time constraints* for their practitioners to complete definitive design. Managing with an open mind means not only questioning everything in practice, but having the courage to act on what management see and hear sometimes in new ways. The four areas of practice that improve revenue growth return include *design management, cross-functional talent, iterative processes,* and *end-to-end user experiences*. BSE practice must address design management first if their practice intends to capture the full business value of design.

BSE participants understand that effective management sets parameters by way of performance, allocating adequate resources, motivating their team by commitment, understanding and ethos. Connecting the right people to the project, thus building upon *practice reputation*. In essence, their embracement to provide practitioners with a collaborative, supportive and comprehensive working environment leads to a satisfied client and repeat work. By association, management demands a clear understanding of the project brief, thus delegating tasks effectively to achievable deadlines. There is a need for management to *understand the limitations of their team,* whereby their transparency on real deadlines is conveyed without concealment. *A safe-pair-of-hands to deliver client's demands and good at working with people* are paramount traits of competency in BSE management. This mannerism demands foresight, and clearly communicated to practitioners in a non-blame working environment. Conversely, the lack of interpersonal skills by managers induces reluctance by practitioner to communicate amongst peers effectively. *Management-by-example* with technical and social skills places trust in their practitioners to deliver projects, thus inspiring a team that works well together. Management who holds both tacit and explicit knowledge in their field are ideal candidates to lead a team.

Programme and Cost Control participants are adamant that management demands an understanding of practitioner technical know-how by allocating the right practitioners and trade experience to foresee and effectively address problematic issues in a concise manner. Management need an adequate skillset with focus on work-wins, which commands an understanding of the projected workload to sustain their practice. Moreover, Mechanical and Electrical Contractor participants concur that BSE management require a high level of technical and social capability, whilst being approachable to discuss project delivery within a non-blame culture. Practice management must align programme constraints with their practitioners by involving them in the initial design process to express innovative ideas. Practitioner ability to say *no* is important, whilst endeavouring to meet challenging deadlines, but without compromising on quality.

The difficulty in designing complex engineering projects does not arise from technical complexity, but from the managerial complexity, necessary to manage the interactions between the different disciplines, thus imposing further challenges in the design process (Yassine, Falkenburg, & Chelst, 1999). All participants agree that early communication with *actual* client and stakeholder, and understanding their requirements is key to deliver a successful project. BSE participants believe that their design tasks are *totally* dependent on digital constructs, and indeed, their *over-reliance* in design software without understanding the intrinsic *real* design considerations. Thus far, it is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme (Sugumaran & Lavanya, 2013). BSE participants estimate that an additional 40% - 50% of the total work hours in practice may be required to rectify such deficiencies. BSE participants' experience infer that limited service fee assigned to the design stage can often lead to a *race-to-the-bottom* scenario, whereby competitive fees can compromise design quality. Practitioners admit a lack of understanding of installation costs.

Shrewd Mechanical and Electrical Contractors can *steer-a-ship through the design gaps*, but with intent to secure additional costs for their benefit. Allocating adequate time and resources at design stage would minimize a negative impact at construction stage. Depending on project complexity, inadequate resourcing results in additional time spent at construction stage. The *right people* using the *right digital technology* could minimize such disparity. Mechanical and Electrical Contractor participants wholeheartedly agree that poor design documentation leads to *disruption and carnage* at construction stage. The percentage of time or cost to *rectify design shortcomings* is modest at the design stage, but the time and cost to rectify the same shortcomings is *tenfold* at construction stage. Mechanical and Electrical Contractor participants promote their early engagement with BSE management to collaborate in *joint-design reviews*. Allowing the Mechanical and Electrical Contractor to review and provide input into the design can ensure certainity in pricing and accuracy in design. This early design-construction team interaction could minimise potential problems and maximises efficiency in practice, whilst adopting a *constructability strategy*.

Programme and Cost Control participants concur that problems initiated at design stage incur deficiencies at construction stage. It was highlighted that incomplete design on private sector projects is more problematic at due to the allocation of provisional sums, where there is often a consequential onus on BSE practice to perform technical coordination at installation stage.

In contrast, public sector projects demand fully coordinated design prior to tender intended to mitigate design gaps, thus negating additional cost that could potentially be borne by BSE practice. There appears to be *a lack of awareness* in practice with regard to *contractual claims and commercial strategy.*

4.3.1.6 PRACTITIONERS

The literature quantifies that 85% of project success is due to management personality in terms of communication, negotiation skills, whilst 15% is due to technical knowledge (Carnegie-Mellon-University, 2016). This assertion also vetoes how practitioners perceive project success, whereby they believe that personality is more superior to technical knowledge in order to gain *respect* from peers and stakeholders alike, thus surmising further inadequacy in a technically-biased educational system.

BSE participants view that a strong practitioner-client relationship is imperative to successful practice, whereby both professions hold strong technical initiatives and behavioural characteristics. A technically competent manager with good interpersonal skills is imperative for successful delivery of quality design, as opposed to one with solely technical knowledge. Recruiting by *goodness-to-fit* in practice, practitioners' technical knowledge is vital at initial professional levels, but the importance of personality surpasses at managerial level. Poor performance at any level fragments the team, thus creating friction and weakening client relationships. A vibrant management delegation regime supports a well-balanced *technical savvy* team during the design process.

Programme and Cost Control participants view BSE management with strong interpersonal skills and an openness to communicate and negotiate on design principles are imperative to business success. Thus far, the misuse of technology can initiate inefficiencies in practice, where theoretical design parameters are assumed, but in fact *real world* parameters are different.

Similarly, Mechanical and Electrical Contractor participants take a 50-50 stance in terms of management hard and soft skills. As practitioners transition from design to management, the prerogative for personality, communication increases, with their ability to manage effectively in an open positive form.

It is also suggested by the Mechanical and Electrical Contractor participants that the removal of the *traditional blame-game* is replaced with a *team-resolution* approach by enabling onsite teams to make decisions quicker and deliver projects sooner by the use of digital technology (Koutsogiannis, 2020). Interestingly, Mechanical and Electrical Contractor participants believe that BSE management currently depend on site foremen to provide direction on system installability.

Theorists suggest that 80% of waste in engineering practice is due to managerial incompetence, particularly how management request practitioners to carry out tasks, whereby the link between practitioners and their deliverables is a complex series of social and technical interactions (Trevelyan, 2007). Most BSE participants disagree with this account, suggesting that they are given the freedom to utilise their individual technical problem-solving skills and methods. However, a number of BSE participants believe that inefficiencies are primarily generated by management failing to communicate the complete design intent from the project outset, and not realising the *knock-on* effect in the design process. Moreover, BSE participants believe that there is an element of complacency in the management process, which is instigated by *default* management. There is a lack of foresight by management to over-design and unnecessary deliverables to the lack of awareness on cautionary repetitive design. There also appears to be a direct correlation between the efficiency of completing assigned tasks and practitioner experience, whereby more prescriptive tasks should be assigned to less experienced professionals.

BSE participants also believe that management who hold tacit and explicit experience are reluctant to adopt modern digital design methods and processes. In fact, the *sporadic* role out of emerging digital technologies can lead to miscommunication of design intent amongst practitioners. A *technological change management process* is seen as the key to tracking inefficiencies and deficiencies at design and installation stages, respectively. This improved design planning process could initiate an effective management strategy, not only providing clear communication of in-house project variables, but disseminating vibrant communication to other disciplines, thus negating the negative impact at construction stages. BSE participants also sense that the design process could be improved, where management place trust in practitioners to attend focused client briefings meetings unaccompanied.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS					
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**		
			BSE PRACTICE	PROGRAMME & COST CONTROL	MECHANICAL & ELECTRICAL CONTRACTORS
PEOPLE	Practice and Academia	Themes	➢ Evolving education system to prepare graduates for engineering practice ➢ Apprenticeships in conjunction with academia ➢ Inadequate practical experience for graduates ➢ Graduate unaware of multidisciplinary role ➢ Adopt a collaborative and comfortable communication ➢ Trusting team environment ➢ Harmonious team	➢ Trade experience at undergraduate level enhances practice knowledge ➢ Creative and supportive ➢ Technology upskilling required ➢ Work-placement for real exposure to office dynamics	➢ Irish education system does not adequately prepare graduates ➢ 80% academia and 20% practical placement schemes ➢ Open communicative team culture ➢ Positive mental attitude
		Differences	➢ Absence of holistic design approach in engineering practice ➢ Client engagement through practice experience during academia	➢ Perception that BSE practice contains practitioners with craftsman's background ➢ High quality professional service	➢ Higher education institutes focused on new technology software rather than being led by current digital constructs in practice ➢ Limited design fees hinder problem solving at construction stage
	Knowledge Generation	Themes	➢ Unnecessary over-complicated design ➢ Formal training from BSE practitioner to management ➢ Management deemed as a career by default ➢ Management evolves from design experience and technical know-how ➢ Management lack an understanding of the design process ➢ Tacit and explicit knowledge is imperative to management success	➢ Management self-disciplined with career progression in mind ➢ Practitioners *naturally* ascend to a managerial role ➢ BSE management transition by experience	➢ Investing in peer mentorship ➢ Unaware of consequential BSE practice dysfunction ➢ Early engagement with design team ➢ Project team confidence-building ➢ Off- and on-site separation between BSE practitioners lead to mis-communication
		Differences	➢ Underestimation of client's technical knowledge ➢ Design process is deemed intangible	➢ Design is perceived as *tangible* ➢ Technical and practical knowledge variance at installation stage	➢ Forced adoption of a design-oriented BIM ➢ Black-and-white approach at installation stage ➢ Financially driven
	Reflective Practice	Themes	➢ Adaptation of lessons-learned ➢ Reflective practice improves design ➢ Lack of management to advocate the importance of multidisciplinary design ➢ Dependence on Mechanical and Electrical Contractors to rectify design issues at construction stage ➢ BIM process improves communication and reflection process	➢ Reflection attributes to self-development and professional competence	➢ Time constraints to reflect restricts reflective practice ➢ Silo working environment ➢ Dependence on Mechanical and Electrical Contractors to rectify design issues at construction stage ➢ Multidisciplinary practice is more collaborative than non-multidisciplinary practice with strong management
		Differences	➢ Fear of self-criticism ➢ Practice hiding behind technology ➢ Multidisciplinary practice is more collaborative than non-multidisciplinary practice ➢ Absence of formal reflection ➢ Constructive criticism in design approach ➢ Improvement in design practice by both reflective and experience	➢ Mitigate copy-and-paste design approach ➢ Management has greater client focus than design	➢ Self-reflection and reflecting on others' experience improves project delivery

Figure 49 *Preliminary data analysis summary – People (Part 1)*

Programme and Cost Control participants believe that there is inherent practice *waste*, where practitioners work under unreflective direction. The lack of managerial and communication skills initiates rework with cost implication. How management communicate tasks to their practitioners from client and project briefings is imperative to minimise waste in practice.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS					
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**		
			BSE PRACTICE	PROGRAMME & COST CONTROL	MECHANICAL & ELECTRICAL CONTRACTORS
PEOPLE	Learning in Practice	Theme	➢ Management awareness of half-life of engineering knowledge ➢ Insufficient time for adequate formal training ➢ Project demands hinder formal learning ➢ Practitioners value training and mentoring ➢ Learning-by-collaboration	➢ Management responsibility to facilitate learning in practice	➢ Project demands hinder formal learning ➢ Digital technology aspirations hindered by demands ➢ Well-regulated formal training programme management
		Differences	➢ Learning through formal and informal training programs	➢ Large-scale practices have a greater capacity to invest in learning in practice	➢ Competent assured mentors to prepare for chartership status
	Management in Practice	Theme	➢ Succinct management direction ➢ Poor delegation from management ➢ Inadequate communication ➢ Management reluctant to request adequate time at design stage ➢ Design practice dysfunction initiated by practitioner inexperience, lack of mentorship, and lack of appreciation of site constraints ➢ Adequate resource allocation ➢ Understanding limitations of their team ➢ Lack of management interpersonal skills ➢ Early client engagement	➢ Incomplete design at tender stage initiates programme and cost impact at construction stage ➢ Adequate resource allocation ➢ Early client engagement	➢ Poor client-BSE management relationship ➢ Management requires high standard of technical and social capability ➢ Early client engagement
		Differences	➢ Inefficiencies at design stage are only realised at construction stage ➢ Onus on Mechanical and Electrical Contractors to resolve design issues at construction stage ➢ Non-blame attitude and culture to practice ➢ Practice dysfunction at 40-50% ➢ Management lack in understanding of installation costs ➢ Competitive fees can compromise design quality	➢ Variance in design between public and private sector clients ➢ Problems initiated at design stage incur deficiencies at construction stage ➢ Management lack of awareness to project contractual and commercial strategy	➢ Poor technical coordination as opposed to poor design ➢ Advocate early contractor involvement at design stage to mitigate cost issues at construction stage ➢ Develop a constructability strategy at design stage ➢ Management-practitioner collaboration to innovate
	Practitioners	Theme	➢ Inadequate technically-biased educational system ➢ Personality surpasses technical attributes at managerial level ➢ Lack of foresight by management to over-design ➢ Management reluctant to adopt modern technology ➢ Technological change management process ➢ Inadequate briefing by management	➢ Misuse of technology initiates inefficiencies in practice ➢ Lack of managerial and communication skills initiates rework with cost implication ➢ Inadequate briefing by management	➢ Practice inefficiencies arise from out-dated industry practice
		Differences	➢ Disagreement that 80% of waste in engineering practice is due to managerial incompetence ➢ Complacency in the management process ➢ Management place trust in practitioners	➢ Client management	➢ Traditional blame-game is replaced with a team-resolution approach ➢ Inexperienced practitioners often initiate waste ➢ Lack of design responsibility

Figure 50 *Preliminary data analysis summary – People (Part 2)*

Similarly, client management is paramount to ensure the design brief is succinctly captured prior to design, thus avoid redesign. It is envisaged that the art of clear client communication embraces effective management to yield higher utilisation rates and an efficient working environment, where practice strategy encompasses good utilisation to promote work-wins in the right market.

Mechanical and Electrical Contractor participants relate practice inefficiencies to *out-dated industry practice*. They expect engineering management to set out the design criteria, define the methodology used to solve technical issues, and allocate competent practitioners initiative. They believe that this is not always the case, where inexperienced practitioners often initiate waste.

Mechanical and Electrical Contractor participants are also adamant that *regular communication negates misinterpretation*, and that BSE management should request early feedback from all project disciplines to ensure that their message was received and interpreted correctly. Based on project complexity, feedback could be managed in the form of a 30/60/90% feedback on the staged tasks. Surprisingly, Mechanical and Electrical Contractor participants often view management *who pass down their dirty work to over-worked practitioners* with limited time to resolve, thus resulting in further error and waste.

4.3.2 PROCESSES

4.3.2.1 DESIGN MANAGEMENT

Competitive service fees can result in unrealistic time frames forcing BSE management to tighten the design process by attempting to achieve the same milestones with less information (Portman, 2014). BSE participants allude that this inadequacy has a *knock-on* effect by expediting the design of one discipline, thus impacting other disciplines' schemes, and gives rise to inaccurate tender documentation with *serious* consequential deficiencies at construction stage. Design issues cannot be resolved by squeezing the design process. BSE participants were wholly aware that a *rammed* design process leads to inefficiency, but they advocate that with an enhanced *technology-driven* design, management is in a position to improve the process. Their belief that increasing the design time not only mitigates shortcomings at installation stage, but also improves relations with the Mechanical and Electrical Contractors and the greater project team. There is an *amplifying* concern that resources allocated in the design process is generally low compared to other disciplines, where it is perceived that the delivery of modern construction projects is demanding shorter building programmes.

Achieving milestones with competitive fees leads to poorly coordinated design. Ensuring that the right people with the technical and digital know-how in understanding of scope of works and programme is imperative for successful project delivery.

Management advocate that their practitioners must understand the greater design team's variables to guide appropriate deliverance. Surprisingly, management seldom take cognisance of project variance, and assume similarities to past project delivery, which introduces further risk in terms of design quality. There is a perception that management often do not recognise the full positive impact of digital delivery, which is deemed detrimental to practice. A number of BSE participants believe that *honest design delivery in a transparent manner* yields greater efficiency, and mitigates design errors or omissions.

From an experiential perspective, Programme and Cost Control participants concur that squeezing the design process has an unfavourable effect at construction stage; *shortening the design process never works.* There is a direct correlation between squeezing the design process and increased costs at construction stage, but they admit that value engineering often favours the design process in terms of programme implication.

The affirmation to allocate sufficient time and injecting fee into the design stage achieves design quality, and helps to nullify expensive contractual claims. There is a general consensus amongst Mechanical and Electrical Contractors participants believe that a *push to an unrealistic tender date* instigates insufficient coordination resulting in significant delays at construction stage, but they fear that rushing the design process is *part and parcel* of the construction industry in Ireland. Mechanical and Electrical Contractors participants also surmise that inadequate design peer reviews places *progress in front of quality, and* ultimately resulting in *additional time and cost at the back end of a project*. However, as some projects allow additional time to facilitate design development, the completion date generally remains the same, thus results in *a squeezed install and commissioning programme.* In the real-world, *programme is pressure* that leads to problems, and attempts to address design gaps at pre-construction stage are generally scarce.

BSE practitioners accept that the design management process is a logical, dynamic and complex progression due to its multidisciplinary nature, which requires technical competence and collaboration to ensure that MEP systems are designed effectively, thus providing a good quality building within reasonable cost and programme to meet or exceed clients' expectations. However, the design process is perceived differently amongst technical and non-technical practitioners as *logical thinking* to *fulfilling client aspirations*, respectively.

Despite Programme and Cost Control participants admit to understanding the process, they believe that their input is not required until the design is complete.

The Mechanical and Electrical Contractor participants acknowledge that the design process is *ever-evolving*, which infers that the design process does not specifically conclude once the design is fully detailed at pre-construction stage, thus contravening theorists design principles. Programme and Cost Control participants deem incomplete design has a significant impact at construction stage, which leads to deficiencies at construction stage, particularly in terms of programme and cost, but suggest it is not in their remit to engage wholly with BSE practice at design stage.

Mechanical and Electrical Contractor participants surmise that Programme and Cost consultants should have greater involvement to *vet design* to *initiate cost surety*. Notwithstanding this, Mechanical and Electrical Contractors welcome their early engagement in the design process with both BSE management and Programme and Cost consultants to *optioneer and to hone-out the best solution* in terms of cost, installability and constructability. This additional realm to the BSE design process would mitigate *inexperienced BSE consultants* from producing *vague design*, which ultimately, impacts the remaining project stages. Moreover, BSE participants believe that the *whole* adoption of BIM has the potential to digitise the technical coordination by addressing installability concerns, thus negating the requirement of early contractor engagement.

The current BSE design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage, thus consequential dysfunction in practice. By implication, BSE participants often experience *silo design* or *designing-in-packets* during the design process. They caution the adoption and augmentation of previous designs, which could negatively impact subsequent project phases. Practitioners view that design shortcomings are normally discovered at installation stage by Mechanical and Electrical Contractors.

Interestingly, BSE participants believe that *inadequate management of service fee distribution throughout the project life cycle* can lead to practice dysfunction. This anomaly could be addressed by *front-loading the design process* to reduce risk at installation stage. *A healthy start* at design stage is imperative for successful delivery of subsequent stages. They expressed concern that resource planning is extremely challenging due to other ad-hoc project commitments. Moreover, practitioners are perceived as being generally well-educated, talented and skilled, but they can possess *different mindsets* that initiate design miscommunication.

It is envisaged by BSE participants that a strategic role-out of BIM in practice could improve this environment.

Programme and Cost Control participants advocate that *lessons-learned from past projects* should be adopted to new projects to minimise practice dysfunction, whereby practitioners are made aware of their contribution to inefficiencies, and negate thereafter in subsequent project delivery. They believe that the design process demands a wholly collaborative working environment in order to produce a suite of accurate design documentation. Admittedly, programme pressure appears to *kill the design process* by not allowing sufficient time for practitioners to collaborate effectively.

Mechanical and Electrical Contractor participants surmise that inefficiencies are normally down to *out-dated industry practice*. Notwithstanding that BSE management set out the design criteria, their methodology adopted to design is normally addressed by the practitioners' own initiative. In the absence of an independent peer review, issues only *come-to-light* at installation stage, where costs are incurred to rectify the situation.

The key to accurate design is *appropriate practical experience*. It is advocated that it is easier to fix a problem on paper initially than nearing the end of the installation. The trend of aggressive programme and tight margin in the Irish AEC industry is *forcing progress over quality*, which can yield an overspend in time and money. Mechanical and Electrical Contractor participants understand that BSE Practice has a tendency to save their design stage service fee instead of allocating adequate resources from the start, thus expecting Mechanical and Electrical Contractors to address design shortcomings at construction stage.

4.3.2.2 DESIGN PLANNING

Design is a difficult process to manage and commands effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects may not arise from technical intricacy, but from managerial complexity. BSE participants trust that inherent management addresses day-to-day complex design issues, which requires an *innovative approach*, as opposed to the traditional style. A better planned design process led by a qualified management, applying their *experience with strategic foresight.*

There is an inherent perception that project complexity arising from large multidisciplinary teams with different targets, milestones and design considerations, demands superior planning by management. Undoubtedly, poor management in practice leads to inferior design with consequential delays and cost at construction stage. BSE participants surmise that management by digital *intelligence* constructs alone may not redeem this weakness.

Programme and Cost Control participants concur that the degree of complexity in delivering projects is a direct correlation to technical intracity. However, early client and Mechanical and Electrical Contractor engagement is perceived to simplify the design process by prompting practitioner technical savviness to deliver a coordinated design. Similarly, Mechanical and Electrical Contractor participants believe that deploying a strong and multidisciplinary communication process instils a collaborative design practice environment. Projects overseen by a single *time conscious decision-maker*, and with transparent communication between design and construction professionals, risks can be reduced to an acceptable level.

The BSE design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management. BSE participants perceive that such problems are initiated by *individual incompetence*, a *lack of understanding for system installability*, *a lack of appreciation for end-user requirements* in an *unclear design process*, which leads to inferior design solutions and a lack of technical coordination. As poor design data impacts cost and programme at construction stage, BSE participants believe that a structured independent peer design review could alleviate those phenomena. However, there is an undue concern that such reviews are often subjective, whereby reviewers are not wholly aware of design considerations. BSE participants are also cognisant that issues are more easily resolvable at design stage with negligible impact compared to determination at construction stage.

It was stated by BSE participants that approximately *80% design accuracy* is common practice, where practice place dependence on Mechanical and Electrical Contractors to resolve any design deficiency. Conversely, there is a consensus amongst BSE participants that a direct correlation exists between a *squeezed design programme* and inefficiencies and deficiencies at design and construction stages, respectively, suggesting that design development *really takes place* at construction stage, whereby the collation of Mechanical and Electrical Contractors and BSE practitioners resolve design issues.

Interestingly, Programme and Cost Control participants believe that undermining management is rare in construction practice, and advocate that complex *technology-driven buildings* require higher technical and management capabilities. However, they perceive that inadequate data gathering at design stage imposes issues downstream resulting in practice dysfunction. They believe that prompt client briefing mitigates *double-handling* in practice. On the other hand, Mechanical and Electrical Contractor participants believe that management is unquestionably dependent on digital software to manage the design-construction interface, and concur that the quality of design to deliver a successful project correlates to the positive interaction between the design and construction teams. Despite the *traditional site liaison* to resolve installability issues can be effective, this process appears to be replaced with a digital administrative protocols. Mechanical and Electrical Contractor participants also advocate that a silo working environment in practice tends to promote a *kicking-the-can-down-the-road* phenomenon when design problems arise, thus challenge BSE practitioners to precisely *vet* the design to identify gaps to minimise future risk at construction stage.

4.3.2.3 PROGRAMME, TIME, VALUE, RISK, QUALITY AND PERFORMANCE MNGT

Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. It was observed by BSE participants that BSE programme management is seldom prioritised before architecture on most projects, which can lead to *weak design*. In fact, BSE is generally the last input in the BIM design process, which often initiates dissonance between other disciplines by demanding rework of their respective design. By including BSE design into the overall programme earlier, paves the way for an improved design process. Complex technical projects, such as data centres, whereby BSE practitioners manage the programme, are generally *better led* by technical *know-howers*, as opposed to non-technical programme managers.

This strategy tends to yield a positive outcome from a technical perspective, but there is less emphasis on cost and contractual issues, which could prove problematic for the greater project delivery. BSE participants perceive that through the *art of smooth management*, there is a *deep bias* in the AEC industry to BSE leading projects. Traditionally, building programmes are managed by architects and structural engineers with modest BSE input.

Mechanical and Electrical Contractor participants advocate that *marrying each disciplines' design on a continual basis* into one *whole design* during the design process *minimises waste*, and delivers a successful project. Mechanical and Electrical Contractor participants were adamant that inherent design coordination intricacies arise only when incomplete design is recognized at construction stage, with is often only rectify by their intervention. Moreover, client instigated changes at construction stage can overlook the true impact on installation. It was suggested that the preposition to *fabricate off-site* would demand *unchangeable* concise design at design stage, thus negating *any* design changes at construction stage, which would ultimately improve the programme management process.

Performance measurement provides a means of distinguishing between perception and fact at individual, project and practice levels. A significant question for design performance measurement is whether improvements in design alone can lead to changes in performance. BSE participants confirmed that performance measurable tasks are not normally defined by management at the project outset, acknowledging that delivering the project *within the fee* is the only performance management stipulation. Participants suggest that feedback from the greater design team would be a useful indicator of their performance on past projects.

Individual performance assessment is generally conducted by performance management with a reward process in mind, which is often informed by a structured annual process, whereby practitioners set practice and professional goals, and management apply a rating to practitioner achievements. From a *project* perspective, Programme and Cost Control participants believe that performance is principally measured *on commercial acumen,* and indeed, where practice is deemed to add value to the project through identification of savings, thus rebuffing claims in accordance with good contract administration. In addition, the performance of BSE practice is perceived by BSE participants as a measurement by time, quality, collaboration and commitment to the project, but surprisingly, excludes a technical competence metric. The people metric is also excluded despite practitioners wholeheartedly express that a project completed *on-time with dissonance between practitioners* is not a successful project.

BSE participants surmise that practice strives for constant improvement, but this endeavour is often impeded by *financial constraint.* Resource allocation in accordance with the design and building programme are often measured from a practice financial perspective, which is deemed the key performance indicator. Moreover, BSE participants advocate that a *balance between financial and design quality* would be a more suitable key performance indicator in practice.

In many instances, practice performance is difficult to measure accurately due to the fast pace of the Irish AEC industry.

Interestingly, Mechanical and Electrical Contractors performance is measured by acquiring BSE design to produce an *end-product* within programme and budget, quality of installation, health and safety record, project complexity with client's satisfaction. Mechanical and Electrical Contractors *individual* KPIs outlay appraises the level of individual competence and career progression. At *project* level, it is measured on roles and responsibilities being delivered, which *maps-up* the respective KPIs, thus mapping their overall business strategy.

Supporting the client from project inception to understand their issues and perceptions in terms of articulating their requirements is an imperative facet to engineering practice (Trevelyan, 2010). BSE participants advocate that this engagement is highly dependent on clients' technical knowledge, and correlates to the quality of the project. A client with the technical *know-how* can often hinder the quality of design by demanding *their way of doing things,* whereas a client with a non-technical background gives a design team *freedom* to develop their individual design subject to agreed design parameters.

BSE participants believe that a well-informed client in the context of technical, commercial and programme, generally benefits the overall design scheme, but practitioners must be in a position to *steer-the-course* of the right level of design. *On the contrary,* uninformed clients can lead to *watered-down design,* or indeed, *overdesign.* Late engagement with the client can lead to a delayed design process, and in some instances, design issues are pushed-out to construction stage, which incur additional cost and time delays. There is a consensus between BSE participants that a direct correlation exists between early client engagement and the quality of design produced. A succinct brief is essential to initiate an effective design process, thus *realisation of clients' expectations.* Limited client-practitioner engagement induces an unclear design brief, and by association, a true understanding of their expectation.

Programme and Cost Control participants concur that early client engagement *lays the foundation stone* for the remaining stages of project delivery, and advocate that this liaison is crucial in interpreting an accurate brief to deliver a successful project. *The sooner the practitioner-client bridge is built and communicative flow is established, the higher the efficiency of the design process*. This early engagement brings a healthy interface between an informed-client for design success.

Interestingly, Mechanical and Electrical Contractor participants take a cautionary stance to early client engagement, and advocate that project success is wholly *dependent on clients' true knowledge*, which can mitigate against the *I-want-this, that-and-the-other approach.* However, Mechanical and Electrical Contractor participants believe that by adopting a BIM process at design stage, whereby aligning clients with the design team could aid in visualising the end-product, thus facilitating the development of a strong brief. This process also gives Mechanical and Electrical Contractors a *degree of comfort* knowing that the design intent is costed accurately. Mechanical and Electrical Contractor vow that *weakness* in the *design process* needs to be addressed imminently to negate practice *reputational and commercial damage.*

4.3.2.4 TECHNICAL COORDINATION

Technical coordination in BSE practice infers management working with and influencing practitioners so they conscientiously perform necessary work to a mutually agreed schedule. This position was echoed in all interview participant responses in their belief that mutual understanding of design intent between disciplines throughout the design process is paramount to a successful project.

This is particularly predominant when rational adjustments to design are initiated, thus positively reducing design and coordination uncertainty and ambiguity that may develop in this complex web of multidisciplinary professionalism. With mutual understanding of the client brief, the act of coordinating technical work of other people by gaining their willing cooperation is a major aspect of engineering practice. BSE participants believe that partial implementation of design with constant technical coordination, and *ongoing live connection between disciplines* through digital constructs could truly mitigates against rework. This collaboration is imperative at design stage to avoid deficiencies at construction stage. The lack of understanding of this phenomenon leads to *frustration between practitioner disciplines*, and ultimately practice inefficiency.

This scenario often arises when practitioners are limited to attend all client meetings to understand their design expectations. Management is obliged to disseminate a thorough understanding of the brief to its practitioners during the design process by communicating accurate project deliverables to ensure multidisciplinary adherence.

There was a consensus amongst BSE participants that the adoption of the BIM process could facilitates this live technical coordination process. BSE participants believe that practitioners also need to be cognisant that other disciplines' teams have different variables, such as team dynamics, management and resources allocated to the project. BSE participants acknowledged that technical coordination with architectural and structural engineering constructs is challenging due to the dynamic nature of building design. The key facet of this process is mutual agreement by the design teams to *freeze* the building model, thus negating an uncoordinated design.

Programme and Cost Control participants also surmise that the adoption of digital technology is paving the way for an improved collaborative working environment in the AEC industry. Articulation, communication and cooperation amongst practitioners to produce a *well-technically coordinated design* by *effective management*, who have the technical know-how and transparent communication skills. The demise of these attributes could inevitably result in additional cost at construction stage. Mechanical and Electrical Contractor participants concur that mutual understanding of the design intent between disciplines and specialisms is paramount in delivering a successful project. On occasions where design intent changes, should be communicated by management to practitioners with reasoned explanations. Developing a close-knit team encourages an *all-for-one and one-for-all attitude*, which benefits the project team when faced with looming deadlines. Strong team communication promotes accurate technical coordination to align design deliverables with the overall programme.

Design coordination is a purposeful and goal-oriented activity, which aims to coordinate all service design activities, processes and resources in practice. Its inherent failing is known for ill-definedness and complexities, which result as a lack of information (Simon, 1977). The design coordination process is also intended to allow each discipline to compare their respective materials that are intended for a given space in a building to ensure they will not conflict physically or impair the installation and maintenance of subsequent systems.

BSE participants argue that design coordination is performed primarily by BIM technologists with varying levels of effort and results. This affirmation of sorts surmises that design is driven by engineers, but the result is delivered through the hands of others. Conversely, there appears to be an *over-reliance on digital technology* to address shortcomings in design philosophy. The multidisciplinary awareness of the design process tends to over-emphasis BIM for coordination purposes.

There is also a consensus between BSE participants that regular multidisciplinary collaboration ascertains the optimum design solution, where each discipline take responsibility for their design. The deployment of joint workshops to integrate coordinated design, whether it be architectural on aesthetics, cost management on cost or contract, or fire safety engineering. The ability for management to *speak the same language with the same goal in mind* to their practitioners is paramount in delivering an efficacious design. Programme and Cost Control participants reason that design coordination involves BSE management *knowing client expectations* and applying *sound technical knowledge* to yield a *hard* design. A well-coordinated multidisciplinary design *sings-in-harmony,* thus advocating that design coordination entails good communication, mindfulness of programme, awareness of workload and associated timescales and agreeing design activities.

Mechanical and Electrical Contractor participants view design coordination as a *marriage of individual designs* on a continual basis into one whole design in order to deliver a successful project, where multidisciplinary teams' are responsible to coordinate design with *an intention to minimise waste*. Mechanical and Electrical Contractor participants also believe that they facilitate further coordination at construction stage, where design intricacies arise and incomplete design is recognised. They believe that changes instigated by the client at construction stage can equally o*verlook the true impact of delivery,* and perceive that *off-site fabrication* would mitigate against impulsive client requests.

4.3.2.5 INFORMATION AND KNOWLEDGE MANAGEMENT

Information management systems enable the integration of people, processes and data throughout the project lifecycle, thus allowing the secure sharing and storage of project information, whilst enabling practitioners to collaborate effectively and provide project visibility to essentially mitigate risk. This structure ensures that the right information is available when required in the right format (Portman, 2014). BSE participants admittedly *poach* as much of 60-70% of previous design and cost and programme information for new projects as a means to minimise design production time. Consequently, it is imperative that management advocate the use of up-to-date industry standards and specifications, which are easily accessible and understood by their practitioners.

BSE participants also believe that the adoption of BIM industry standards facilitates an excellent common data environment in terms of in-house filing and developing project templates. They advocate the implementation of a logical process to identify, evaluate and quantify, share, manage and monitor potential risks, which may affect the project as a thought-provoking exercise. Most BSE participants admit their contribution in managing risk during the design process, but *monitoring of risks* is not always evident for the latter project stages.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS					
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**		
			BSE PRACTICE	**PROGRAMME & COST CONTROL**	**MECHANICAL & ELECTRICAL CONTRACTORS**
PROCESSES	**Design Management**	**Theme**	➢ Competitive service fee has a negative affect on the design process, i.e. poor coordination ➢ Tightened design process leads to inefficiencies ➢ Front-loading the design process by competitive fees ➢ Logical, dynamic and complex progr due to its multidisciplinary nature ➢ Silo design or designing-in-packets	➢ Shortening the design process negatively affects the construction stage from a cost perspective ➢ Programme pressure negatively impacts the design process	➢ Shorter design process leads to insufficient coordination with consequential delays at construction stage
		Differences	➢ Technology-driven design has potential to improve efficiency ➢ Shorter programmes with fewer resources ➢ Assumption by management that project delivery is similar on projects ➢ Management honesty with practitioners on delivery expectation ➢ Introducing BIM to digitise the technical coordination process ➢ Caution in adopting previous design methodologies	➢ Value engineering introduced to mitigate construction cost as a result of inefficient design process ➢ Greater service fee at design stage can mitigate contractual claims ➢ Incomplete design has significant repercussion at construction stage, i.e. programme and cost. ➢ No admission to engage wholly with BSE management at design stage ➢ Lessons-learned approach to the design process,i.e. BSE practice awareness of inefficiencies at design stage.	➢ Inadequate peer review at design stage negatively impacts design quality ➢ Attempt to address design gaps at pre-construction stage is limited ➢ Design process is continuously evolving ➢ Design process does not conclude at design stage ➢ Programme and Cost consultants to assess design at design stage to initiate cost surety, and instigate optioneering, where necessary ➢ Out-dated industry practice ➢ Appropriate practical experience of BSE practitioners ➢ Mechanical and Electrical Contractors to address design shortcomings at construction stage
	Design Planning	**Theme**	➢ Innovative approach to design ➢ Digital intelligence management to redeem design process weakness ➢ Management incompetence through lack of understanding of installability and end-user requirements ➢ Subjective peer design reviews	➢ Technical intracity ➢ Early engagement with client and Mechanical and Electrical Contractors	➢ Early communications with the project team
		Differences	➢ Qualified experienced management ➢ Large multidisciplinary teams lead to management complexity ➢ Design development at construction stage	➢ Complex technology-driven buildings require higher technical and management capabilities	➢ BSE practice totally dependent on digital design software to manage the design-construction interface ➢ Silo working environment promotes risk at construction stage

Figure 51 *Preliminary data analysis summary – Processes (Part 1)*

BSE participants often perceive information management as a *not-reinventing-the-wheel* approach to design. Designing under such professed assumptions can introduce risk, whereby the adaptation of a concise information management process by cross referencing past projects could expedite the design process. However, caution is expressed, whereby management must be held accountable for their design at subsequent stages. Similarly, where access is permitted to *shared unified files* on past projects, practitioners have a reasonable opportunity to understand lessons-learned, and adapt accordingly if their practice design standards are wholly maintained.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS					
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**		
			BSE PRACTICE	**PROGRAMME & COST CONTROL**	**MECHANICAL & ELECTRICAL CONTRACTORS**
PROCESSES	**Programme, Time, Value, Risk, Quality and Performance Management**	**Theme**	➢ BSE programme not priortised ➢ BSE design is the final input in BIM Revit modelling process ➢ Predominant technical projects managed by technically competent practitioners – can lead to cost and contractual issues ➢ Performance measurements not normally provided by management to practitioners ➢ Desired performance measurement to be provided by external design team ➢ Client technical know-how relates to quality of project delivery ➢ Early client engagement	➢ People metric excluded from performance measurement ➢ Early client engagement lays the design foundation stone	➢ Multidisciplinary communication at design stage is imperative ➢ Incomplete design initiates poor technical coordination leading to programme issues ➢ Client changes at construction stage negated by off-site fabrication ➢ Improvement in the design process to negate practice reputational and commercial damage.
		Differences	➢ Performance by fee spend only ➢ Performance not measured by technical competence ➢ Strives for constant practice improvement ➢ Balance required between financial and design quality ➢ Realisation of clients' expectations	➢ Performance measured on commercial acumen	➢ Client changes at construction stage negated by off-site fabrication ➢ Performance measured meeting programme, budget, quality of installation, health and safety record ➢ Performance matched to overall business strategy ➢ Cautionary approach to client expectations ➢ BIM to facilitate early client expectation
	Technical Coordination	**Theme**	➢ Influencing practitioners to a mutually agreed design and schedule ➢ Ongoing live connection between disciplines through BIM constructs ➢ Inefficiency in management disseminate ➢ Cognisant of other discipline teams' dynamics ➢ Deployment of joint workshops	➢ Adoption of digital technology for technical coordination	➢ Strong team communication ➢ Marriage of individual designs ➢ Mechanical and Electrical Contractors responsible for the design coordination at construction stage
		Differences	➢ Design coordination is performed primarily by BIM technologists ➢ Over-reliance on digital technology		➢ Design coordination involves knowing client expectations
	Information and Knowledge Management	**Theme**	➢ Design poaching from previous projects to minimise design process time ➢ BIM Common data environment to manage information	➢ Appreciation of digital information management database	
		Differences	➢ Risk monitoring at design stage, but not at construction state ➢ Management accountability for design ➢ Lessons-learned from past projects ➢ Digitalisation often demands practitioners to start design without the ability to adopt previous design schemes		➢ Design poaching from previous projects introduces high risk at construction stage.

Figure 52 *Preliminary data analysis summary – Processes (Part 2)*

Initiating the right information management process to achieve a high-quality design commands efficient internal auditing and quality procedures to *get-a-grip* of practitioner design intent, and where appropriate, adapt past-project experience to new projects to realise greater proficiency at design stage. BSE participants believe that the digital evolution is transforming practice, but its constructs somewhat demands practitioners to in fact reinvent-the-wheel, whereby their design must start from scratch without the ability to *poach* previous project schemes.

Moreover, Programme and Cost Control appreciate a practice that develops a digital information management database with *standard libraries* containing reference documents and solutions, and by adapting through continual correction and modifications is better-equipped to deliver design in an efficient manner.

Mechanical and Electrical Contractor participants formidably believe that 60-70% of information from previous design is adopted by BSE practice for new design project. Despite good design may be prescribed by lessons-learned, they warn BSE practice not to *lose-out where they lost-out before*. They express undue caution to practitioners, where out-of-date industry standards and specifications can be easily mismanaged, thus leading to shortcomings at construction stage. Similarly, Mechanical and Electrical Contractor participants advocate that design anomalies could only be addressed outrightly by ensuring that the right people have access to the right information, which is clearly understood.

4.3.3 TECHNOLOGY

4.3.3.1 DIGITAL SMART AND CONSTRUCTS

The introduction of specialisms in BSE practice, such thermal modelling (TM) and computational fluid dynamics (CFD), has paved the way for *silo* working in a multidisciplinary environmens, which provides further challenges. Traditionally, BSE practice is viewed as a *dark-art* due to its multidisciplinary nature, whereby BSE participants experience a *silo-specialism phenomenon.* This trend is mostly evident in large multidisciplinary practices, whereas smaller practices tend not to rely on external specialists. BSE Participants expressed concern that current practice is veering towards each practitioner being a *one-for-all* by adopting a *blanket-design approach*, which is deemed *not practical* in modern practice.

Moreover, the introduction of stringent building regulations has led to a more onerous design process, whereby external *default specialisms* are emerging, thus enhancing the *siloed-discipline design.* The drawback of this approach is that it is difficult for practitioners to be held *accountable* for the overall design.

Programme and Cost Control participants believe that a more collaborative team approach is vital, where specialisms are introduced, and acknowledge that their input normally improves the quality of design. Admittedly, integrating specialisms into a collaborative team can i*nstigate challenges,* and lead to technical coordination issues, and by implication, additional cost at construction stage. Programme and Cost Control participants also advocate that digital technology is having a positive impact on the design process, thus facilitating greater accuracy in technical coordination. Mechanical and Electrical Contractor participants concur that digital technology has the ability to improve this digital *silo* trait, and suggest that practice could benefit by creating an *open-forum communication culture* to reduce barriers formed by a silo working environment.

4.3.3.2 DIGITAL GOVERNANCE AND TRANSITION

The literature affirms that the complete BIM adoption to building design is imminent by enabling practitioners and stakeholders to instantly collaborate on an integrated design platform, thus practices that depend on 2-D design will be at a professional disadvantage.

BIM is about moving away from traditional industry practice of producing multiple and independent paper-based documents that describe what a building is, it is an endeavour to create a virtual building design. However, BSE participants explain that the transition from 2-D to 3-D design is a *painful* one. Its adoption demands greater time to coordinate the 3-D model at design stage, which ultimately incurs higher costs to the design team. BSE participants reveal that although working in a collaborative environment is valuable, sharing the BIM model with non-technical disciplines is not a straightforward activity. The process dictates that BSE practice requires other technical discipline designs to be complete prior to their input, including architecture and structural engineering. Participants also admit that a major challenge to 3-D modelling is *representation*, whereby 3-D detailed design must be well advanced preceding final development of 2-D drawings. This is a significant drawback for BSE practice, who aim to produce respectable work-in-progress drawings during the design process.

BIM adoption is in its infancy in the Irish AEC industry. BSE Practitioners expressed concern, particularly where not all design team partners are equipped with this digital construct, and that the *knowledge base or readiness* are *lacking amongst the design team*. Practice *time and cost challenges to 3-D design adoption* are evident, and there is a consenting concern that consultancy fees do not reflect this transition. BSE management often downplay *real* resources required associated with BIM delivery, thereby leading to inadequate fees.

BSE participants believe that BIM adoption raises management challenges, where a technical knowledge gap may exist between the practitioner and technologist, thus advocating that technologists need to understand the design intent to implement 3-D design in an effective manner. Continuous ad-hoc changes by other disciplines in BIM is difficult to manage. Interestingly, practitioners can often *hide behind 3-D design* when such changes are implemented by other disciplines. This change process demands BSE management to enforce stringent tracking to avoid abortive rework, and by association, practice dysfunction.

Programme and Cost Control participants express that it is a *challenging endeavour to persuade* the Irish AEC industry to heavily invest in digitalisation due to *limited incentives* available in the present-day commercially competitive environment. Programme and Cost Control participants welcome 3-D BIM approach not only to provide an accurate visual guidance on intricate design, but to expedite their uptake in the BIM process by extrapolate data through a cost measurement digital construct. They judge that the relatively *slow-uptake* in BIM is principally related to clients *not recognizing the value of BIM* and *industry research*.

There is ongoing contractual reliance on 2-D documentation to cost design, where Programme and Cost Control participants believe that BIM is a developing paradigm with weaknesses, but predict its positive benefits will be realised in due course. In contrast, Mechanical and Electrical Contractor participants analogise the transition from 2-D to 3-D with *pencil drawing to 2-D AutoCAD*, and they fear that the flow of information to generate an *installation* model without their early engagement will always be problematic. They are confident that upskilling *all* design and construction professionals will alleviate this concern, thus their advocation that successful BIM adoption will only transpire by *training tradespeople*, which will enhance the technical coordination process, and support clash resolution prior to installation for *progression and buildability* at construction stage.

4.3.3.3 DIGITAL PRACTICE

Engineering design is often too complex to carry out manually due to the significant number of variables. The use of digital tools to predict outcomes can somewhat mitigate against human error through manual calculation. BSE participants accept that such digitalisation is adopted with an air-of-caution in the context of accuracy, and mandate that their design is checked by experienced practitioners, who apply their professional tacit experience to this explicit design process.

A number of BSE participants believe that their design is totally dependent on digital constructs, and admittedly, they expressed their over-reliance on digitalisation without a true understanding of the intrinsic design considerations. BSE participants insinuate that computational fluid dynamics (CDF) software *does not reflect real-world*, and is dependent on accurate input parameters, which are often *difficult to define* to simulate a realistic design model. Similarly, this intimates that thermal modelling (TM) provides *good design guidance*, there is an inherent reliance on many unknown variables, such as *people behaviour, building operation, weather conditions and building construction materials*, to achieve an *exact* simulation. Equally, the use of digital tools in the propensity of power distribution, general and emergency lighting, lifts, lightning protection, heating, ventilation and daylight simulations, wind and solar energy, are adopted on the side of caution.

Moreover, MagiCAD, a powerful illustrative mechanical and electrical system design tool integrated with BIM, offers BSE practitioners an influential digital means to save time, whereby its application promotes a more user-friendly, flexible, intelligent, and parametrical design environment. BSE participants accept that its concept is *brilliant* for elements of design, but caution that its adoption demands intensive training to *reap* real rewards. BSE participants also highlight concern relating to limited knowledge in integral BIM design by peers in practice, who may not be wholly familiar to conduct an accurate design review. There is also hesitancy in its uptake due to a dependency of procuring equipment details from third-parties, thus preventing practitioners to maintain absolute control over their design. Notwithstanding this, BSE participants advocate that a planned-adoption approach would not only enhance asset and information management, but improve *productivity* and *proficiency* at design stage. Interestingly, its wider adoption and skill-set development could facilitate the amalgamation of the *practitioner-and-technologist into one role*, as opposed to the traditional *two-people* design delivery approach.

However, there still exists an adverse *ingenuity-versus-technology* in design practice particularly amongst experienced practitioners and management. Most worryingly, deep caution was expressed by BSE participants, whereby practitioners can often be *creative* in persuading *digital software to give the right answer* adopting digital tools. There is an overwhelming belief that practitioners must be wholly cognisant of first-principle theory that underpins digital design. BSE participants advocate that manual checking using such first-principles assists design accuracy. The assertion to define the right input parameters at design stage yields *less-hassle* at construction stage, thus reflecting positively on the design process.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS					
CATEGORY	RESEARCH TOPIC	CODING	MATRIX		
			BSE PRACTICE	PROGRAMME & COST CONTROL	MECHANICAL & ELECTRICAL CONTRACTORS
TECHNOLOGY	Digital Smart and Constructs	Theme	➢ Silo-digital specialism phenomenon ➢ Independent practitioner design environment ➢ Siloed-discipline design	➢ Digital specialism culture is not collaborative	➢ Siloed-discipline design
		Differences	➢ Management reluctant to take accountability for practitioner design	➢ Digital technology is having a positive impact on the design process ➢ Collaborative approach to digital design	➢ Open-forum communication culture to negate a digital silo working environment
	Digital Governance and Transition	Theme	➢ Transition from 2-D to 3-D is challenging ➢ More time required resulting in higher fee spend	➢ Limited incentive by AEC industry to invest on digitalisation ➢ BIM is a developing paradigm with weaknesses	
		Differences	➢ BIM requires digital expertise; not all the design team is digitally astute ➢ Work-in-progress design difficult to demonstrate in the BIM process, as BSE design is the final input in the federated model ➢ Management challenge where technical knowledge gap exists between practitioner and technologist ➢ BSE management to take responsibility for design adjustments	➢ BIM process could expedite cost measurement ➢ Slow uptake due to client not recognising the value of BIM	➢ Analogise the transition to BIM as from pencil-to-2D ➢ Cautionary towards the use of BIM for installability purposes without their early engagement during the design process. ➢ Upskilling of tradesperson required to enhance the technical coordination process on site
	Digital Practice	Theme	➢ Digitalisation adopted with an air-of-caution ➢ Design review by experienced practitioners or qualified management ➢ Digital upskilling is imperative ➢ Over reliance on digitalisation without understanding intrinsic design - first-principles theory		➢ BSE practice is over-reliance on digitalization ➢ Lack of BSE knowledge to interrogate design output
		Differences	➢ Reliance on unknown variables in digital modelling ➢ Lack of planned-adoption approach to digitalisation (framework) ➢ Digitalisation to amalgamate practitioner-and-technologist into one role ➢ Constructing digital model to give the right answer ➢ Resort to external specialist for digital design modelling		➢ Management design review who understand design from a practical and technical perspective

Figure 53 *Preliminary data analysis summary - Technology*

This cautious adoption of digital constructs, whereby *gut-feeling first principles* and *understanding of design fundamentals* can deliver rational design more effectively. Interestingly, BSE participants admit *resorting* to external specialists to provide digital design representation. Mechanical and Electrical Contractor practitioners perceive digital design as very useful, but believe BSE practitioners are *over-reliant* on its paradigm. The perceive that digitalisation is welcomed in BSE practice, and believe that BSE practitioners' ability to interrogate the output of these design decision-making tools is questionable, whereby the design *outcome is only as good as the user applying* the software. They concur that experienced management require *an understanding of the basics with practicality* to assess such digital outcomes, thus ensuring that *no human errors* or *over-design* have occurred.

Although this research on technology in BSE practice is qualitative in nature, the discussion thus far, yields a strong correlation to the quantitative findings from the literature review, where barriers to BIM implementation principally relate to lack of client demand, lack of collaboration, expertise and training, limited time to upskill, selective projects, and more importantly, the absence of an established BIM framework in the Irish AEC industry *(Figure 26).*

4.4 REVISED FRAMEWORK

The preceding discussion parallels the theoretical constructs with the empirical research, and is deliberated chronologically principally by the interview method by converging *people*, *processes* and *technology* that highlighted additional problems in BSE practice, which were interpretated by the researcher to understand their origin. The theoretical path in this research ultimately focused on understanding the empirical design process in practice by applying triangulated data principally from interviews to test the various components of the theoretical framework *(Figure 39).* The responses to the structured, open-ended interview questions delved into the fundamental values and evolution of the BSE design process to gain an understanding of each participants' perception of management, descriptors, education, experience inside and outside the design process, and success in BSE practice. The researcher also assessed the case-study documentation and their reflective journal for corroboration purposes.

Further propositions, highlighted in blue, were derived from this theory-test to produce a *revised* management framework (Cavaye, 1996) *(Figure 55).* The evidence synthesised thus far reveals that BSE management underperform at design stage, which was found to be a major source of problems at construction stage; this failure leads to significant dysfunction impact in practice. This key finding is a direct consequence of management perceived as the information bottlenecks, misalignment of design across disciplines with no concentrated effort to specify client requirements and uncertainty in information flows, lack of collaborativeness and discussion of design alternatives, low proportion of value-adding activities, and the lack of competency in adopting digitalisation in the design process.

BSE practice tends to spend the greatest amount of time on detailed design with considerably less time spent on preliminary design, thereby gaining a perception from the design team that the BSE input requirements at the early design stage is minimal. In general, practice devotes significant time on processes inefficiently, such as producing design documentation, but not collaboratively generating and exploring digital design alternatives to maximise value. Unquestionably, the most significant activity drawback in practice relates to the amount of practitioner time spent on rectifying design issues at construction stage, which ultimately, leads to practice dysfunction. The primary methods and tools used to plan, organise, design and manage the design process appear to be inadequate. This empirical research reveals that management tend to focus the *who, what, and when*, as opposed to pure efficient design, where management acknowledge that design is essentially a social and technical activity.

The triangulated focus on people, processes and technology ensures that BSE management create an effective design process with a team consisting of *people* with relevant education, skills and experience, who are committed to conducting staged *processes* throughout the project life, and supported by suitable *technology*.

Participants believe that commitment from management to instil constant learning through practice, academia and professional institutes at design and construction stages permits better people doing better things in a better way. The competitive nature of professionalism in Ireland raises further challenges in retaining tacit knowledge in practice, which can often result in design inefficiency when experienced practitioners depart. A well-oiled practice will always face an element of dysfunction, but applying lessons-learned for past experience and allocating appropriate reward and resources can alleviate this affliction. Moreover, by conducting detailed design reviews by independent peers prevents repeat shortcomings and project failures.

Participants advocate that the Irish AEC industry now demands that BSE management view the design process as the multidisciplinary activity, where digital constructs could be adopted to increase efficiency and develop the inherent social-technical dualism to improve practice. Participants also argue that managing the client's expectations is paramount in the endeavour, Management that work with the client to ascertain a clear design brief, and who cascade systematically to their multidisciplinary practitioners is paramount in protecting BSE practice. Moreover, clients are expecting the AEC industry to implement the BIM process, where open 3-D modelling and the nature of collaboration are appealing, and where accuracy, minimum waste and requirements are adhered.

Furthermore, participants viewed that sustainability in design represents design outputs driven by modelling technology, which are dependent on theoretical input variables. However, it is expected that a greater emphasis by modern practice management would evoke superior sustainability in design to creating a context focused sustainability strategy at the project outset.

Thus far, the research implicates that by understanding, adopting and implementing these further propositions, BSE practice is in a unique position to govern through a modern management framework. The researcher is wholly cognisant that a robust management framework can only be finalised by testing its validity, whereby a broader dataset was procured by conducting interviews with seasoned professionals in five leading Irish BSE consultancy practices.

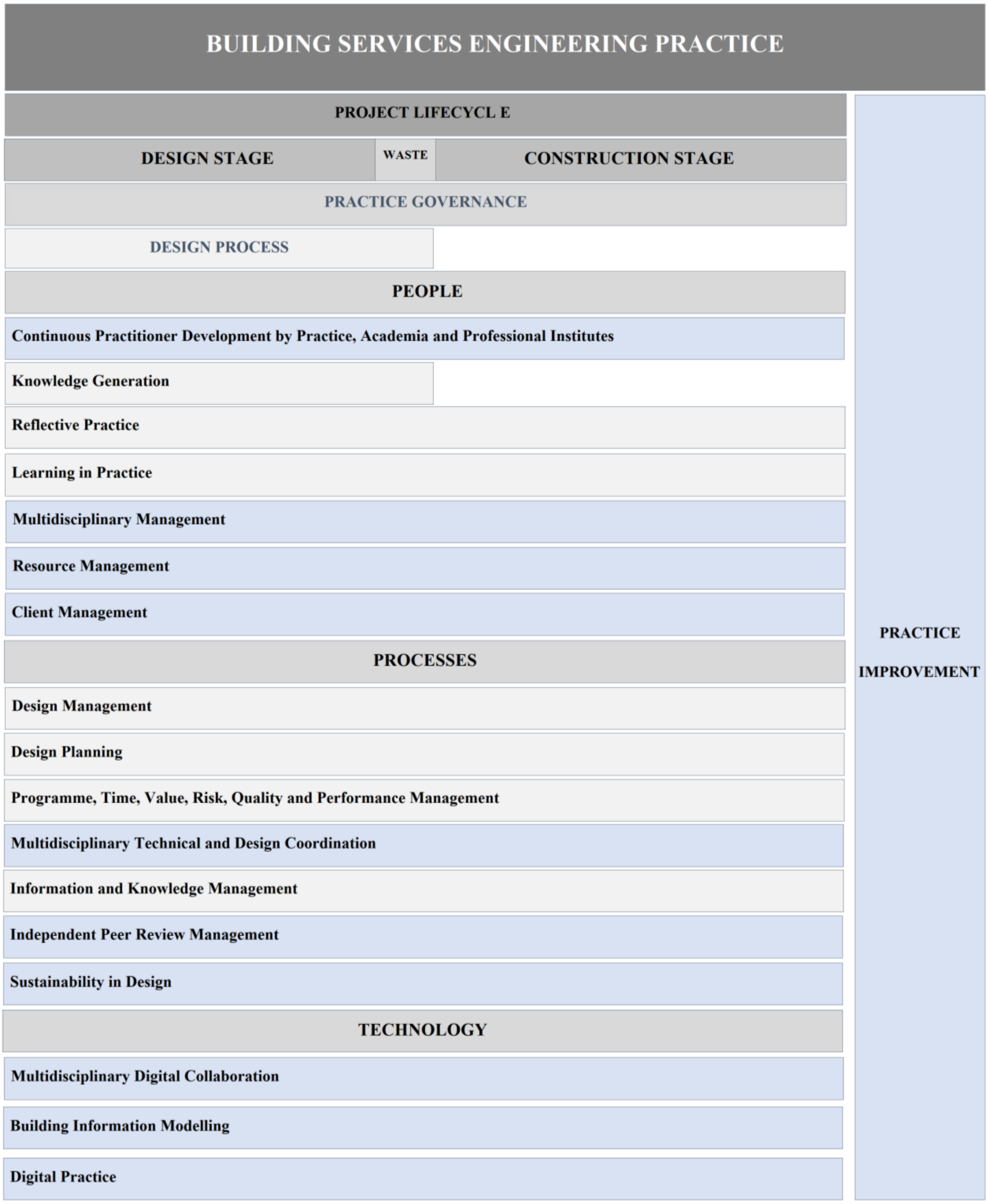

Figure 54 *Revised framework for BSE management*

4.5 RESEARCH VALIDATION

The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process, and by implication, its inherent management practice. The BSE industry is wrestling with this productivity gap, and the time has come to embrace innovation.

Thus far, this practice-based research has exposed current practice to develop a management framework, which is intended to establish an improved design process by the proficient convergence of people, processes and technology in practice *(Figure 51).* To this end, the overarching research outcome suggests that management now has the key to unlock the future by ensuring that their BSE team consists of people with relevant education, skills and experience, who are committed to conducting staged processes throughout the project life, and supported by suitable technologies.

Examining the validity of the forgone inquiry is a key component of this research methodology (Taherdoost, 2016). The more rivals and alternative explanations that the analysis addresses, the greater the credibility of this research, thus contributing to the body of knowledge (Yin, 2003). Accordingly, external BSE management were queried on how their practice would benefit from this innovative triangulated focus between *people*, *processes* and *technology.* For consistency purposes, structured, open-ended interview questions related to *people, processes* and *technology* were presented to five seasoned professionals from leading BSE practices in Ireland *(Figure 48) (Appendix 19).* This purpose of this validation process was to test a number of components on the revised framework, analyse the participants' responses, and amend the revised framework, if necessary, to produce a final BSE management framework. A summary of the validated data analysis in BSE practice is presented in *Figures 55*, *56* and *57*, respectively. In addition, all participant interview transcripts and initial analysis are contained in *Appendices 20 and 21*, respectively. The quotes used to substantiate the researcher's claims from the empirical analysis was presented in ***italics*** to differentiate them from their own words.

4.5.1 PEOPLE

4.5.1.1 PRACTICE AND ACADEMIA

It is affirmed that the Irish educational system does not adequately equip graduates with hard and soft skills for BSE practice. By implication, the lack of practical digital experience in the respective curriculum is a significant weakness, which still sees graduates *living in a 2-D world*. Participants describe how their practice bridges the gap between *knowledge and employment reality* when graduates are inexperienced in digitalisation and corporeality.

In this association, practice would welcome greater engagement with higher education institutes to employ better-equipped graduates to negate *training from scratch after initial employment.*

An inherent variance amongst education institutes in providing their undergraduates with digital tutelage has instigated practices to introduce the BIM process on their graduate training programme. However, this endeavour demands *heavy investment*, but it is expected to improve practice in the foreseeable future. Graduates with limited knowledge on digital constructs required *intense learning* with varying degrees of success. Conversely, participants acknowledge that there is merely partial advantage of BIM training in education, where undergraduates are not entirely positioned to fully appreciate the practical side of the AEC industry. Notwithstanding this, participants recognise that it is their responsibility to professionally develop their graduates, but they encourage that undergraduates must understand the fundamentals of their discipline on entering practice.

4.5.1.2 LEARNING IN PRACTICE

Practices are expected to invest heavily in adopting new digital constructs, whilst training their practitioners to operate that technology efficiently. Sustaining the implementation of digitalisation requires extra effort from management with their openness to deliver quality design in the format of transferable digital information. This adoption process is never instantaneous. Instead, it is dependent on management who are more responsive to embracing new innovates.

Interestingly, participants believe that Engineers Ireland tend to focus on architectural and structural engineering constructs, and consequently, BSE practice resorts to *service providers* to provide practitioners with continuing professional development seminars as new technologies become available. However, the Association of Consulting Engineers of Ireland (ACEI) is in the process of developing an industry standard design process, which is expected to include digitalisation. Participants trust that these ACEI stipulations will not only advance the design process, but ultimately, mitigate practice from being *railroaded by clients* during the project life cycle.

Participants expressed concern with regard to emerging *unapproved* digital technologies available in the current market, which leads to *slow adoption* of the greater digital quest. Notwithstanding this, most participants offer structured graduate training programmes, which is intended to upskill their practitioners in *soft-and-hard* industry practice skills. There is a strong regard to *train from the ground upward* with a strategic focus on *categorised lessons-learned* in digital adoption. This tutoring process is principally driven by *unequipped graduates* who are *inadequately trained in digital engineering constructs* at higher education institutes. Furthermore, practices are now adopting a cross/disciplinary learning approach to deploy frequent *knowledge sharing*, *learning-bursts* and *refresher training* with *external influence* for management and practitioners. Participants surmised that practitioners are embracing digital transformation greater than management despite the national effort to incorporate digitalisation in the AEC industry.

4.5.1.3 MANAGEMENT IN PRACTICE

It is acknowledged that practitioners work in silos albeit being cognisance of the critical interface required between other discipline designs. However, it is argued that this interchange of data is not clearly advocated by management. Participants concur with this practice experience, and elaborate that negating this phenomenon delivers more successful projects. There is a genuine consensus that *small practices tend to be hands-on* with greater communication, whereby early ironing-out of design gaps is often more feasible.

Participants advocate that management tend to place *higher priority on external multidisciplinary collaboration* rather than negating their in-house silo working environment. It is believed that the *real* adoption of BIM will bridge this multidisciplinary practice gap. Remarkably, the participants observe architects as being reluctant to recommend some BSE practices due to their poor reputation in discipline coordination. In fact, there is regular resentment by other disciplines, whereby architects perceive BSE practice as a *black art.* This status-quo often leads to practice *raising their bar* to demonstrate greater competency through quality and experience. Accordingly, the ongoing challenge to improve technical coordination and collaboration between disciplines is at the forefront of practice. However, participants admit that BSE management tend to prioritise their *professional interest ahead of in-house operations*.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS			
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**
			EXTERNAL BSE PRACTICE
PEOPLE	Practice and Academia	**Theme**	➢ Inadequate Irish education system to equip graduates with hard and soft skills ➢ Inadequate practical digital experience ➢ Practice bridges gap between technical knowledge and practice reality
		Differences	➢ Practice has introduced the BIM process on graduate training programmes ➢ High investment cost of training graduates in digitalisation ➢ Graduates lack full understanding of fundamental principles of BSE practice
	Learning in Practice	**Theme**	➢ Extra effort by management to train practitioners ➢ Engineers Ireland focus on architectural and structural constructs
		Differences	➢ BSE practice depend of MEP system providers for training ➢ Association of Consulting Engineers of Ireland intend to roll out digitalisation roadmap to AEC industry ➢ Unapproved digital technologies in the Irish AEC industry leading to slow adoption ➢ Management slow to adopt digital constructs
	Management in Practice	**Theme**	➢ Silo-working environmental ➢ Management to advocate multidisciplinary interchange of data ➢ Management place higher priority on external multidisciplinary collaboration ➢ BIM process has the potential to improve collaboration
		Differences	➢ Hands-on approach to the design process in smaller BSE practices ➢ Architects perceive BSE practice as a black-art ➢ Management tend to prioritise their professional interest ahead of in-house operations

Figure 55 *Validated data analysis summary - People*

4.5.2 PROCESSES

4.5.2.1 DESIGN MANAGEMENT

The inherent productivity gap at design stage leads to inferior quality of systems’ installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in practice.

It was intimated by the participants that this is *not a new phenomenon*, and that shortcomings at design stage are instigated by a *bad design team*. It is management's *professional obligation* to negate deficiencies at construction stage by adopting a *design-it-once and design-it-right* philosophy. The participants believe that management must display *pride in nailing-down their design,* but be cognisant of the *architect's ever-changing design model,* which *introduces programme creep and increased costs*. Human nature often initiates late decision-making by differently opinionated disciplines**,** and coupled with *building complexity and shorter design programme*, can negatively impact design coordination. Moreover, client ambiguity at design stage results in design gaps leading to consequential deficiencies at construction stage.

Interestingly, practice often *sell themselves short* due to competitive fees, and becomes *problematic when delivering a professional project with non-professional fees,* resulting in the use of junior practitioners to deliver detailed design. This leads to *hidden inefficiencies* in practice. BSE participants acknowledge that the productivity gap is often subjective with a direct correlation to *practitioner variance.*

4.5.2.2 TECHNICAL COORDINATION

It is hypothesised that inferior BSE design leads to programme delays and additional costs at construction stage. This phenomenon not only affects MEP installation, but also traverses to other discipline trades, including structural engineering and architecture. Participants advocate that each practice is obliged to technically coordinate under their contract terms, and stipulate that public projects demand greater *coordinated design at design stage*.

By contract, private projects demand *greater coordination at construction stage*. As SC have limited design experience, this initiates problems at construction stage for the latter. However, it is also surmised that BSE practice is habitually dependent on *good calibre contractors* to rectify their design shortcomings at construction stage. Traditionally, practice has *relied on noble contractors to technically coordinate at installation stage*, but participants advocate that this scenario is now *thinning*. The perception that practice wholly perform *scant design* and *hand-over responsibility to the contractor* is vehemently denied. The introduction of the Building Control Amended Regulations (BCAR) in Ireland has thus improved this discernment amongst design teams.

Nevertheless, participants warn that a stigma still exists in the Irish AEC industry that *bad-design is a result of poor BSE design coordination*, and argue that its possibly *good design, but poorly coordinated*. It is encouraged that regular independent peer design reviews ensure precise technical coordination. Furthermore, participant wholeheartedly accept that *digitalisation will prompt* this process in an efficient manner.

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS			
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**
			EXTERNAL BSE PRACTICE
PROCESSES	**Design Management**	**Theme**	➢ Practice dysfunction is not a new phenomenon initiated by incompetent management ➢ Deficiencies at construction stage negated by design process improvements ➢ Client ambiguity at design stage results in design gaps ➢ Productivity gap at design stage is subjective dependent on management effectiveness
		Differences	➢ Management pride in role by embracing collaboration to avoid practice dysfunction ➢ Human-error resulting in late design changes ➢ Professional project with non-professional fees results in hidden inefficiencies during the design process ➢ Lack of confidence amongst BSE management
	Technical Coordination	**Theme**	➢ Greater priority of design coordination at design stage on public projects ➢ Greater priority of design coordination at construction stage on private projects ➢ BSE practice depend on good calibre Mechanical and Electrical Contractors ➢ Independent peer design review is imperative ➢ Disagreement that BIM technologists are principal technical coordinators ➢ Dual role of BSE practitioner to design and technically coordinate; negating the future role of dedicated technologists
		Differences	➢ Full coordination at construction stage by Mechanical and Electrical Contractors is vehemently denied ➢ Building Control Amended Regulations (BCAR) has placed full responsibility on design teams to technically coordinate during the design process ➢ Digitalisation if expected to improve the technical coordination process

Figure 56 *Validated data analysis summary – Processes*

It is reasoned in practice that design coordination is in fact performed primarily by technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end-result is delivered through the hands of others. Participants reveal that their practice protocol in delivering design coordination is the *ultimate obligation of each engineering practitioner*, and believe that *BIM technologists are not designers*, they are *digital tracers*. Agreeably, all participants deny that concept design is solely conducted by practitioners, whilst technologists develop the design in 3-D BIM. However, a recent practice trend reveals that practitioners are now preforming this dual role. Participants envisage that BIM managers will exclusively manage the BIM process, whereby practitioners will be design in BIM, thus negating the need for dedicated project technologists.

4.5.3 TECHNOLOGY

4.5.3.1 DIGITAL CONSTRUCTS

The BSE design process is aided by the use of computer models, which simulate the performance of thermal behaviour, energy usage, electrical distribution, vertical transportation, ventilation, renewable energy resources and artificial lighting. By association, research indicates that occupant productivity, wellbeing and happiness increase if they work in an environment with good lighting, and comfortable temperature and air circulation (Kelly, 2020). Participants were probed on their experience with the accuracy of these prediction tools. Their experience is most positive when used decorously, but acknowledge that there is a direct correlation between their outcome and *knowledgeable practitioners*, which ultimately, demands further validation and verification by management, who apply their experience to this explicit process as *rules-of-thumb and benchmarking.*

The use of prediction software tools can often mitigate against human error from manual calculation, and accordingly, practice is open to adopting new digital constructs, but participants strongly advocate that *digital providers would be benefit from conducting post-occupancy evaluations to ascertain actual qualitative performance of buildings*. At present, feedback is measured from *FM complaints*, which is an inappropriate benchmark. Moreover, an element of complacency exists, whereby the accuracy of digital tools depends on practitioner understanding of input data.

Participants were also questioned to what extent their practice relies on predictive modelling, and surprisingly, they vehemently denied total reliance on predictive modelling, thus advocating *greater reliance on the accuracy of the principles of engineering design*.

Digital software brings a *degree of accuracy* with impending interrogation, but participants believe that this digital process requires experienced management and practitioners to understand the correct inputs and predicted outputs, thus intimating *poor information-in, poor information-out.* However, there was an admission by a number of participants, whereby management often over-reliant on digital software to produce *comfort* design. Whilst complete digital design is imminent in practice, The general consensus reveals that management must take responsibility for a thorough review process at input and output stages.

More recently, the use of VR and AR technologies can positively influence the design review process by immersing management in full scale simulations of the design, thus facilitating early identification of issues to increase program surety, effective management of risks, minimise rework and reduce issues during the construction stage. By blurring the lines between the physical and digital world, participants were questioned how their practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence.

In general, practice has initiated the adoption of VR and AR for *complex design schemes* and *client presentation purposes*, as opposed to practitioner benefit. Participants alluded that the average client does not understand drawings, and that this 3-D representation offers a conception of the building's physicality, where coordinated multidisciplinary design can be assessed with their involvement. This digital construct essentially offers the client *an appreciation of their service purchase*. The adoption of VR and AR is also used by practice as a *marketing and sales-type approach*. Participants believe that AR and VR is currently *architecturally driven* from an aesthetics perspective, but its use will be more prevalent in future BSE practice. Furthermore, there is a consensus that its accuracy is questionable at present, as it *struggles to keep up-to-date with visualisation* of BSE software and devices in *complex data hungry models*.

4.5.3.2 DIGITAL SMART

BSE management is cognisant of the so-called half-life of technical knowledge in engineering practice. Whilst most of their practitioners are normally keen to evade this outdated status, many do not share this vested interest, whereby they disclosed that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

Participants were queried how their practice harnesses technological advances to keep abreast with digitalisation in the Irish AEC industry. Most interestingly, participants concur that the turnover of digital tools is substantial, and promote discipline knowledge as the best tool in acquiring design capability and competence. Nevertheless, there is a consensus that practice must keep abreast of developments in digital technology, make time for dissemination of technological advancements, and advocate cross-practice sharing of digital knowledge. Practitioners and technologists are often tasked with lecturing and training their peers, which most challengingly, dictates the allocation of increased budget and time for digital training. Interestingly, participants believe that traditional design knowledge-saturation in practice is prompting innovative digital strategies.

The introduction of a practice digitalisation roadmap by management is imperative in developing practice, including the appointment of a *digital champion* to liaise with professional institutes, higher education institutes, Industrial Development Authority (IDA) and Enterprise Ireland (EI) to standardise a digital training programme. This roadmap may also include BSE equipment manufacturers, who are deemed a good source in disseminating advancements in digital technology.

4.5.3.3 DIGITAL GOVERNANCE

There is a consensus that complexity in building design has paved the way for the *digital engineering evolution*. Traditionally*, non-digital practices have worked*, but there is an err of caution in suggesting that this evolution increases productivity. A number a participants acknowledge embracing some aspects of digital constructs in practice, and they estimate that the uptake of 3-D BIM since 2012 is 90% and 2-D AutoCAD is 10%, respectively.Participants believe that current BSE practice is on the *wrong side of the adoption curve (Figure 1),* and suggest that *increased resources and upskilling* is imperative for this transition.

The soar of stringent building regulations demands early input from BSE practice leading to an increase number of specialisms, such as dynamic digital modelling, which is now at the core of practice. Similarly, the introduction of 3-D BIM as a global standard (ISO 19650) somewhat discourages practice from using 2-D AutoCAD.

Interestingly, participants believe that the *traditional practitioner and technologist now commands a single entity,* as BIM process is ultimately design and coordination. The use of *digital technology is welcomed by the Irish AEC industry,* whereby the key benefits include digital file management, paperless practice environment, collaborative digital practice mapped to workflow, and the birth of a digital taskforce to implement digitalisation. Practice management envisage a *full* digital engineering design process, but this transition requires *continual investment* in digital engineering tools without practice governance perceiving this investment as an expense.

4.5.3.4 DIGITAL TRANSITION

Digitalisation is essentially the adoption of digital technology by practice, and the introduction of BIM represents the AEC industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation is difficult to define. Participants evidence their experience thus far with an air-of-caution. Although ACEI recommend BIM for scheme design only, participants are concern primarily with inadequate resourcing, whereby a *greater number of resources* are required to adopt 3-D BIM compared to 2-D AutoCAD. More worryingly, there is an inherent perception that Mechanical and Electrical Contractors reap greater benefits from this endeavour compared with BSE practice. However, the introduction of a global BIM policy has initiated a *change-in-thinking amongst management* to take a *leap-of-faith* towards BIM.

Participants acknowledge that efficiency depends on project type, scale and complexity, and intimate that BIM is most advantageous when design involves repetition, and accordingly, its use is questionable for small projects, where 2-D AutoCAD is deemed more suitable. Notwithstanding this, there is general lack of understanding of BIM in the Irish AEC industry.

It was advocated that non-engineering professionals, including clients, require BIM process training to realise its greatest potential. With a full collaborative project team, it is envisaged that practice will reap efficiencies if BIM is *adopted appropriately*.

Developing and implementing a pragmatic and scalable digital transformation plan is fundamental for improving the design process, thus enhancing the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

Participants were queried how they envisage their practice accelerating digital transformation to expand digital constructs. Their envision toward digitalisation was mixed, whereby it is perceived that the *rate of acceleration of digitalisation will correlate to the size of the practice*. Large practices with research and development departments tend to be at the forefront of digital adoption, principally due their ability to absorb implementation cost. On the other hand, smaller practices are cautious in complete adoption, where it is argued that the provision of a *BIM model does not form a contractual agreement*, and more worryingly, stipulate that there is no practical evidence that building aftercare is directly enhanced by a digitalised design approach.

However, small practices admit that they are tracking efficiency, fee-spend, whilst adopting BIM cautiously, and benchmarking with international design practices with quality assurance in mind. Furthermore, there was a sense of excitement amongst all participants that the adoption of 4-D/5-D BIM could facilitate tracking the entire project lifecycle, which would entice practice implementation. However, participants believe that standardisation of digital transformation is necessary to safeguard BSE practice against unrealistic project team expectations. Furthermore, it is envisaged that reputable accuracy of digital data through BIM modelling will establish practice acceptance to support its adoption, thus pave the way for an improved design process.

4.5.3.5 DIGITAL PRACTICE

Participants reflected on how digital constructs can be effectively and permanently integrated into their practice’s innovation strategy and design process. There is widespread agreement amongst participants that *digitalisation must be embraced to survive in practice.*

However, participants stipulate that *digital innovation will initially* demand *knowledgeable management* to *continually* validate, thus leading to systematic confidence in its potential amongst practitioners. Nevertheless, participants believe that digitalisation is essential in modern practice, the roll-out of a *full digital platform will be a challenge*. They advise that this digital practice journey will not only improve the design process, but will extend to the whole project life cycle. Indeed, a more powerful adoption in digital practice may be achieved by integrative collaboration with Mechanical and Electrical Contractors, but participants question how and when?

Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, thus allowing the secure sharing and storage of project information, whilst enabling practice to collaborate effectively and provide visibility into the project to essentially mitigate risk. However, there is a perception that practice tends to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.

Participants were queried how their practice ensures that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design. Their responses were defensive by strong argument in that their adoption of ISO 9000 Standards obliges practice *to start design from scratch*, and acknowledge that poaching *old designs* is not acceptable in practice as *it leads to risk and mistakes.* However, they advise that it is *difficult to police poaching* amongst practitioners.

To negate design-poaching, BSE practice has developed online libraries to disseminate the latest industry standards and building regulations, thus *ensuring accurate design*. Practitioners are encouraged to reflect on previous design through *a lessons-learned* philosophy, and to adopt an innovative design approach thereafter. There is a mutual agreement by participants that out-of-date regulatory standards can have a significant impact at design and construction stages, and demand that a database containing the latest standards and regulations is managed strictly by a *technical verification team.*

BUILDING SERVICES ENGINEERING PRACTICE BASED RESEARCH DATA ANALYSIS			
CATEGORY	**RESEARCH TOPIC**	**CODING**	**MATRIX**
			EXTERNAL BSE PRACTICE
TECHNOLOGY	**Digital Constructs**	**Theme**	➢ Direct correlation between the output of design prediction tools and practitioner knowledge ➢ Experienced management to conduct peer design reviews ➢ Reliance on management and practitioner knowledge of fundamental design principles rather than technology ➢ Technology brings accuracy to design ➢ VR and AR is architecturally driven ➢ VR and AR accuracy is questioned as visualisation of digital BSE systems often lags behind
		Differences	➢ Digital providers to conduct post-occupancy evaluations to determine accuracy of digital design models ➢ Management reliance on digital design is greater than that of practitioners ➢ VR and AR for complex scheme design schemes, marketing, and client presentation purposes only ➢ Clients' appreciation for VR and AR results from their lack of understanding of design drawings
	Digital Smart	**Theme**	➢ Time and cost constraints hinder enhancement of digital skillset ➢ Cross-practice sharing of digital knowledge ➢ Traditional design knowledge-saturation is prompting innovative digital strategies in practice
		Differences	➢ Substantial turnover of digital tools resorting to discipline knowledge ➢ Management to champion a digital roadmap to standardise a digital engineering roadmap
	Digital Governance	**Theme**	➢ Stringent Irish Building Regulations demands dynamic digital modelling ➢ Introduction of the Global BIM Standard (ISO 19650) discourages 2-D AutoCAD ➢ Continual investment in digital engineering without perception from practice governance as an expense
		Differences	➢ Uptake of 3-D BIM since 2012 is 90% and 2-D AutoCAD is 10% ➢ BIM process demands a single entity in practice as opposed to practitioner and technologist
	Digital Transition	**Theme**	➢ Overall effectiveness of the BIM is difficult to define ➢ Higher number of resources required for 3-D BIM compared to 2-D AutoCAD ➢ Global BIM policy has initiated a change-in-thinking amongst BSE management towards BIM adoption
		Differences	➢ Mechanical and Electrical Contractors reap the benefits of BSE practice adopting BIM ➢ BIM is most advantageous when design involves repetition ➢ BIM adoption demands upskilling of clients and non-engineering professionals
	Digital Practice	**Theme**	➢ Practice innovative digital strategy by knowledgeable management ➢ Full digital platform will be a challenge ➢ Out-of-date regulatory standards can have a significant impact at design and construction stages
		Differences	➢ Implementing ISO 9000 Standards obliges practice to design without adopting design from previous projects ➢ Online libraries to disseminate the latest Industry Standards and Building Regulations

Figure 57 *Validated data analysis summary - Technology*

4.6 MANAGEMENT FRAMEWORK

The findings from the validation process essentially concur with the initial research findings, that is, the evidence synthesised reveals that BSE management underperform at design stage, which results in problems at construction stage, thus leading to significant dysfunction in practice. However, it was surmised that the implementation of management principles through an innovative framework has the potential to improve the design process in practice, as highlighted in green in Figure 58.

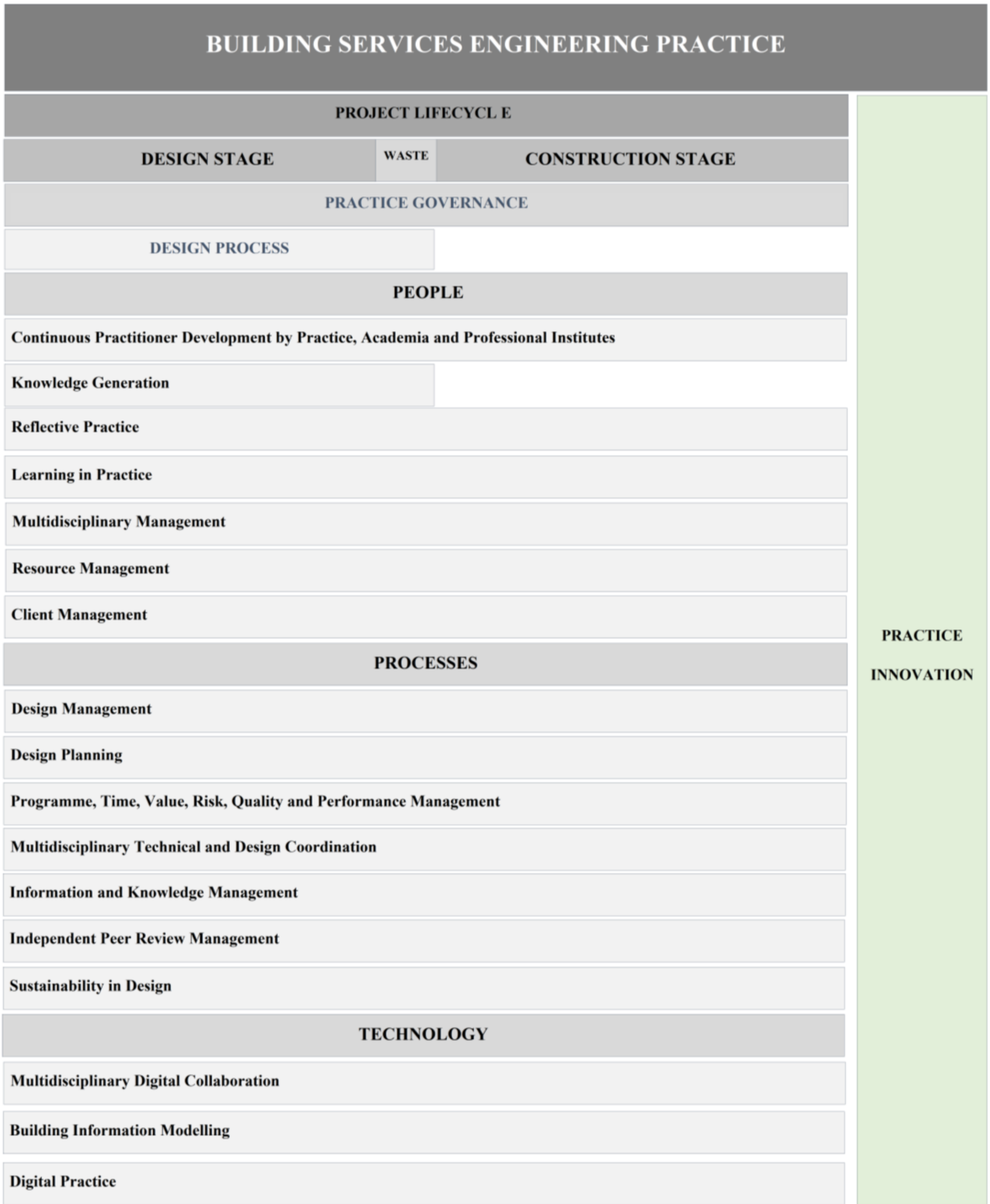

Figure 58 *Management framework for BSE practice*

The BSE design process is fundamentally a function of the quality of the installed systems, which management is positioned to influence by making sense of the complex dichotomy between the design and construction stages that underpins practice. This research focuses on prospective changes to improve the current design process, whereby a management framework has been established to sustain a modern engineering practice *(Figure 58).* More influentially, this framework contextualises that successful project implementation requires an approach that optimises the relationship between people, processes and technology. This strategic triangulated approach to practice management advocates that respective teams consist of *people* with relevant education, skills and experience, who are committed to conducting staged *processes* throughout the project life cycle, and supported by suitable digital *technologies* (Pee, 2009).

Furthermore, this academic and thought management-led research reveals and responds to the critical issues facing the BSE practice in Ireland. In summary, a critique of practice theorises that management, who embrace the convergence of *people*, *processes* and *technology* by assigning the right people to real processes, can potentially transform the current design process through efficient delivery. Whilst the literature review was pivotal in developing a theoretical framework, a further discourse review has highlighted the practicality in managerial effectiveness. Despite inherent complexities and changes ahead, the general outlook is one of positivity, with a commitment from industry peers to maintain resilience in practice.

CHAPTER 5 CONCLUSION

5.1 RESEARCH SYNOPSIS

The research aim to develop a management framework to improve the BSE design process by the proficient convergence of people, processes and technology in practice was achieved by implementing a number of justifiable objectives and respective methods (*Figure 5).*

As the BSE design process is a major source of problems at construction stage, even to the extent of undermining systematic management, managerial practitioners have wrestled with this productivity gap for many years. This research concludes that BSE management who ensure that their team consists of people with relevant education, skills and experience, who are committed to conducting staged processes throughout the project life, and supported by suitable technology are in a position to innovate practice, and dramatically improving the efficiency and quality of the design process, thus sustaining a modern engineering practice.

The research intent was attained by investigating BSE practice in its natural setting, thus unmasking its inherent uncertainty, complexity, instability, and uniqueness of management. By adopting a qualitative approach, this research reflects on the value of subjectivity, constructivism and interpretation by permitting information sharing between the researcher and the researched, thus affording the opportunity to share, learn and generate new knowledge.

A critical literature review provided an academic overview of design management and project management, which was synthesised to BSE management theory to demonstrates how this managerial role influences the performance of activities during design stage, and its impact at construction stage. Modern theory suggests that any unresolved issues at design stage must be resolved at construction stage, which consequently, initiate dysfunction in practice *(Figure 38).* To this end, a theoretical management framework was developed to demonstrated how engineering management could improve the BSE design process *(Figure 39).*

The researcher then examined and tested each component *(practice principles)* of this theoretical management framework with empirical data by conducting a cross-sectional instrumental case study of a practice-based project to gain insight to real engineering management at both design and construction stages.

A revised framework was devised by interpreting this empirical data, which was principally sourced and analysed from structured, open-ended interviews with 15-BSE professionals, and supplemented by case study project documentation, and the researcher's reflective journal *(Figure 54).*

The validity of this revised framework was subsequently tested by conducting interviews with five seasoned managing directors, who were judiciously chosen from five leading Irish BSE practices. Henceforth, the researcher extrapolates a conclusive BSE management framework by adopting the interpretivism paradigm, which put the data analysis in context by relying heavily on interviewing, observation and analysis of existing knowledge *(Figure 58).*

5.2 REFLECTION ON PRACTICE-BASED RESEARCH

The built environment is well established as a recognised field of study by the international academic community. On the contrary, engineering management is an emergent professional discipline, which separates the management function of the methodical design process from the design function, and brings together the technological problem-solving savvy of engineering, administrative and planning abilities to oversee design and construction stages. The doctrine of practice management, whereby management understand how they can minimise waste and create value, is at the central core of this research. The difficulty in designing engineering projects does not specifically arise from technical complexity, but from the managerial complexity, necessary to manage the interactions between the different disciplines, which impose challenges on the design process.

Engineering management inquiry is an increasingly important field of research, one that has a significant contribution to make to decisions about knowledge and skill development of current and future practice. What has emerged from this research is different to that presented in engineering academia, which tends to see engineering practice as being exclusively made up of design, project management or technical problem solving. By contrast, this practice-based research presents a rather more complex portrait of practice, where the interpersonal and the technical are inextricably interlinked *(Figures 9 & 10).* However, scholarship in BSE practice is rare with an insignificant attempt to understand its underlying academic base. In fact, existing literature on BSE management tends to inherently encompass with other disciplines, such as architecture, and does not recognise BSE unique features and idiosyncrasies.

The reason for this academic gap is somewhat explained by the relatively small number of professional researchers who truly understand BSE practice. BSE practitioners recognise and respond to structure, and a well-defined management framework to fully communicate a set of core practice principles has the potential to create alignment, increase understanding and manage a team around a shared and common way of working.

The following content is structured according to the developed management framework *(Figure 58),* where sections and subsections present and describe systematically each component *(practice principle)* by focusing people, process and technology. The quotes used to substantiate the researcher's claims from the empirical analysis is presented in ***italics*** to differentiate them from their own words. As a general rule of thumb, the researcher presented at least two pieces of evidence per claim, which are linked directly to the data.

5.2.1 PEOPLE

5.2.1.1 CONTINUOUS PRACTITIONER DEVELOPMENT BY PRACTICE, ACADEMIA AND PROFESSIONAL INSTITUTES

Engineering is recognised as a technical and a social discipline, both inextricably intertwined. This research reveals that human performance and social interactions lie at the core of BSE practice, and the necessity to understand how human interactions influence technical results. Traditionally, education and training of its practitioners is based on the natural and applied sciences, which tend to create people with *black-and-white* or *right-and-wrong* thinking. This rationale works well when dealing with technical design, but has its shortcomings when dealing with people. Despite theoretical, technical and contractual based subjects being essential to allow undergraduates achieve a high level of academic based knowledge, they rarely have an opportunity to grow their knowledge through experience in practice. This research reveals that an *evolving education system is preparing graduates for engineering practice.* This could be enhanced by exposing undergraduates by *work-placement* to a *trusting multidisciplinary design team* to experience unique *office dynamics*.

Continuous learning in practice is paramount to keeping abreast of modern technology that have entered and are on the cusp of entering the AEC industry, most notably, *the introduction of the BIM process on graduate training programmes.*

Practice bridges gap between technical knowledge and practice reality and indeed *equip graduates with hard and soft skills.* Despite spurring practice innovation and sparking new ideas, which can take advantage to further improve productivity, the *investment cost of training graduates in digitalization* is high. This investment in practitioner education will also provide a more well-rounded skillset to benefit design quality.

Surprisingly, the concept of continuous learning in practice has not yet been mainstreamed. There are several factors why continuous learning is not regularly implemented in practice, most notably, the *condensed design programmes*, *significant workloads* and *limited professional fees* often leave much less time for practice to participate. These deadlines often that get in the way of the professional development, which is so necessary to continue to earn work and grow a practice. This research also concludes that practitioner mentality can also hinder learning, whereby only an open and willing mindset will move practice forward. Nurturing the creativity of practitioners with an open mind is essential, whether in practice or through professional institutes affords them the opportunity to evolve towards innovative career paths and to grasp the strengths of both the old and of the new ways of working to provide a *high quality professional service.* This endeavour demands *extra effort by management.*

5.2.1.2 KNOWLEDGE GENERATION

In its basic form, knowledge infers knowing something with familiarity gained through experience or association. By affiliation, *academic knowledge* is created by scholars and experts in their field, whilst *professional knowledge* is created by combining subject matter expertise with andragogical knowledge. Harvesting new knowledge is considered a precise science, whether it be sourced from academia or practice. The latter advocates plangency within the contemporary discourse about knowledge practitioners and the knowledge economy. This theory-practice test placed different assertions on different kinds of knowledge in practice. More predominantly, technical knowledge which is achieved by remodelling *tacit* knowledge into *explicit* knowledge through practitioner reflection *(Figure 9).*

This is evidenced in the empirical data, whereby *tacit and explicit knowledge is imperative to management success*. However, in the absence of formal training from BSE practitioner to management, management evolves from design experience and technical know-how, *and naturally ascends to a managerial role.*

5.2.1.3 REFLECTIVE PRACTICE

Reflection captures the practitioner's experiences, which is important in learning, and is described as a future-oriented yet retrospective process that encompasses a review of practice, a critical analysis of causes and effects that lead to new understandings and appreciations to draw conclusions to guide future action and behaviour. Reflection in practice represents an activity pursued with intent and consciousness.

The participants call on cognitive and effective skills to perform a reflection process despite *time constraints in practice often restricts reflective practice*. These skills include self-awareness and the ability to describe thoughts and feelings, critically analyse experiences by adaptation of a lessons-learned approach in design practice, whilst attributing to self-development, professional competence, and develop new perspectives. Refection is deemed a crucial process in transforming participant experience into knowledge, and essential for *practice improvement*, even though a *fear of self-criticism exists* amongst practitioners. The thinking process amongst participants was one of the most important issues in this managerial research. When the reflection process is brought into consciousness, intelligent evaluation and decisions were made. However, it is recognised that the interview method did not facilitate interview reflection, and thereby, the researcher did not challenge participants' thinking.

5.2.1.4 LEARNING IN PRACTICE

Learning by experience without reflection is an inaccurate process if mistakes are uncritically repeated. Learning from experience through reflection contributes to the overall mastery in professional practice. Indeed the tendency of practice to continue on the same path is tempting, whereby the failure-to-learn is the greatest cause of practice downfall. The importance of experiential learning as an element of practitioner learning was recognised in this research, where practitioners decide whether they want to feel, watch, think or do in practice. The act of learning in a practice is directly related to how management can stimulate its philosophy. A learning practice is skilled at creating, acquiring, interpreting, transferring and retaining knowledge. A knowledgeable practice works with new ideas, comes up with new scenarios, and implements them by modifying their behavior to respond to new knowledge and insights.

Despite *project demands hinder formal learning* and *awareness of the half-life of engineering knowledge* in BSE practice, this research concludes that *management value training* and *mentoring* through *learning-by-collaboration*, but acknowledge that *large-scale practices have a greater capacity to invest in learning in practice.*

5.2.1.5 MULTIDISCIPLINARY MANAGEMENT

BSE design is a dynamic and complex process due to its multidisciplinary nature. It requires managerial and technical competence to ensure that MEP systems are safely designed, legislatively compliant, and more importantly, technically coordinated in an multidisciplinary environment. It is essential to recognise that this design process involves highly coordinated work, and success relies on effective engineering management to deliver a definitive design under project constraints, including, time, quality, cost and scope. Overlapping of responsibilities in practice is common, where one discipline makes an assumption that the other discipline is undertaking an area of work. It is the lack of a multidisciplinary approach that is at the nature of one of the fundamental problems with BSE design.

This research reveals that BSE practice requires management and their multidisciplinary practitioners to work in a more collaborative manner. This demands changing *outdated design practices* and *adversarial approaches*, and adopt *new technologies* and *methodologies*, in particular, the *BIM process to improve collaboration.*

5.2.1.6 RESOURCE MANAGEMENT

There is almost no limit to the potential of a practice that recruits good people, raises them up as leaders and *continually develops them*. Management is not a right but a privilege to be in a position where one can direct, shape and positively influence their team. Modern-day management operates in an environment fraught with *complexity and change*. BSE practice is beginning to think, rethink and adapt, whereby they recognise that they need to be less hierarchical and more agile with interdependent networks of teams empowered to make decisions. People do not leave practice; they leave managers. Poor management can derail practice operation; *an abrasive manager can do more harm than good*.

Adapting an effective management framework in practice can recompence worthwhile dividends; an efficient manner to mold their teams according to practice core principles *(Figure 58).* This research surmises that for a practice to prosper, it needs *exceptional people with the skillsets,* not only by internal learning opportunities, but externally, where management advocate the *critical importance of a multidisciplinary working environment*.

5.2.1.7 CLIENT MANAGEMENT

Evolving client expectations, influenced by other rapidly changing markets now expect the same from their BSE team to make their brief a reality. Synthesising new technological capabilities are more available making it urgent to separate the more valuable ones from mere novelties. This research reveals that management need to a*ccelerate the adoption of digital constructs* to be at the forefront of this client endeavour.

An innovative practice by digitally transforming the BSE design process has the potential to encourage practice and *clients make better-informed decisions* by using automated knowledge-sharing and generative design techniques that provide multiple design options earlier in the design process. Through standardisation of digital advancements, management is in a position to influence an industry-leading approach to digital design, which permits practitioners and clients to make better decisions with more information, thus producing highly-detailed, construction-ready, designs that could *improve technical coordination* and productivity of the wider design team, thus *reducing dependency on specialist contractor design*, requests for information schedules, change requests and shorten construction programme *(Figure 52).*

5.2.2 PROCESSES

5.2.2.1 DESIGN MANAGEMENT

Management matters most in times of uncertainty and change when practitioners crave clarity. Management demands the ability to seek the best counsel, make firm decisions on the path forward, and ensure that their practitioners understand their role in a shared vision.

This research exposes that management of the design process commands excellent interpersonal skills to communicate, listen, respond and understand practitioners such that inherent problems are more accurately analysed, and the corrective action implemented to achieve the desired outcome *(Figures 51 & 56).* This impact of personality, communication style and technical abilities is reflected in practitioner morale, success level, target, objective and overall attitude in practice. High quality engineering design with sound management is crucial to the success of practice. This research concludes that management believe they *know and understand their business process*, but in reality, *many do not really understand it well enough to judge whether it can be transformed.*

5.2.2.2 DESIGN PLANNING

BSE management conceptualise the design process as a progression of transforming inputs into outputs, a flow of information through time and space, and a course for generating value for the client, which if correctly represented, can be repeated from one project to the next, which can be defined, measured and improved upon. This research concludes that management is deficient in both transforming inputs into outputs, and providing a flow of information through design and construction stages. It is surmised from the empirical data that an innovative approach to engineering design by *adapting digital intelligence management principles*, this process be effectively improved *(Figure 51).*

5.2.2.3 PROGRAMME, TIME, VALUE, RISK, QUALITY AND PERFORMANCE MANAGEMENT

BSE management varies greatly in how projects are conducted. Their performance varies from smooth easy productivity to complete chaos ending in failure. Developing a project delivery programme can be a daunting task for management, but well worthwhile, if modelled through a strategic framework. This procedure facilitates succinct monitoring to control progression during the design process. However, the empirical evidence exposes that the *BSE programme is rarely priortised,* and where the BSE design is often the *final input in the BIM revit modelling process,* which can lead to discord. It is proposed that predominant technical projects must be managed by technically competent programme practitioners.

The most influential factor to a successful design process is the ability to manage time. Interruptions or other demands that impede *real engineering* work, such as limited professional fees, are the enemy. Despite a number of participants suggesting that *administrative activities are a disruption in practice*, this research concludes that interactive activities are critical for the completion of tasks *(Figure 52).*

This research also reveals that risk is unavoidable and present in every engineering project, and refers to the uncertainty that surrounds future events and outcomes. It is the expression of the likelihood and impact of an event with the potential to influence the achievement of objectives by practice. Risk management integrates recognition of risk, risk assessment, developing strategies to manage it, and it is the responsibility of management to mitigate risk to an acceptable level.

Quality management during the design process prevents quality problems by systematic planning of activities, and defines a quality policy with intentions, aims and directions, and monitoring it by a quality control regime. A thoroughly developed process improves the feedback cycle, thus creating a practice self-improving quality regime to increase efficiency and eliminate unnecessary costs from errors and mistakes. Viewed by a number of participants as an administrative process, this research concludes that substantial improvements in meeting quality requirements is imperative in practice.

The iterative and sometimes poorly defined nature of the BSE design process, the lack of information flow, and a number of subjective influences make it challenging to ascertain the benefits resulting from improved performance. Effective performance measurement and management provides a means of improving the design process by distinguishing between perception and fact at three levels; *individual*, *project* and *organisational*. This measurement and analysis of performance indicators are intended to assist management in making more effective decisions, such indicators are difficult to measure in practice. However, this research concludes that practitioners' view of performance relates directly to *financial acumen (Figure 52).*

5.2.2.4 MULTIDISCIPLINARY TECHNICAL AND DESIGN COORDINATION

The key problem facing BSE practice is technical coordination, which requires valuable management to instil an multidisciplinary approach to integrate diverse perspectives into a collective whole. Matters of direction and control in practice are imperative to ensure profitability and the provision of a value-for-money service. However, this research reveals that the prominence of technical and design coordination suggests that management relies on a social process at the microscopic level of individual interactions between practitioners and the wider project team, often far removed from the setting in which practitioners perform their work. Ultimately, management is responsible for creating the right environment to control and support a culture of coordination, and to embrace the complex nature of design involving a multidisciplinary team to deliver robust design solutions by proficient adoption of digital predictive modelling and carefully implementing the BIM process *(Figure 52).*

5.2.2.5 INFORMATION AND KNOWLEDGE MANAGEMENT

Information management ensures that the right information is available when required in the right format, which involves implementing the necessary tools and practices for the collection and management of information from one or multiple sources and the distribution of information to the relevant parties. Practices have recently veered towards cutting edge electronic management systems as an integral part of the BIM process, which store, share and manage design documentation. This common digital data environment enables project data to be accessed by the greater project team at all times for the latest information.

By cutting out wasted effort and time, and doing tasks accurately, the design process can become more productive, and reduce unnecessary and adversarial contract administration and disputes at construction stage. This research highlights that an effective and workable information and knowledge management system is essential to exert managerial control over the design process to improve coordination between engineering disciplines *(Figure 52).* However, the research also emphasises that poor understanding of discipline interdependency of information flow during a project lifecycle is normally a result of disciplines not understanding how their work contributes to the project whole, causing a fragmented managerial approach.

5.2.2.6 INDEPENDENT PEER REVIEW MANAGEMENT

Hazard elimination and risk management are iterative processes, and therefore, changing or developing design requires what to be reduced or mitigated. The key element in effective risk management and compliant design is to undertake hazard elimination and risk reduction as an up-front integrated part of the design process. Independent design peer review meetings are often a useful means for this purpose, whilst also contributing to the effective sharing of BSE specialist knowledge and experience on projects. However, participants regularly perceive that peer reviews are often *subjective as reviewers are not wholly aware of design considerations*. Nevertheless, it is proposed that *two technically-minded independent peer reviewers are required to critique the design (Appendix 21).*

5.2.2.7 SUSTAINABILITY IN DESIGN

Buildings account for a significant amount of global greenhouse gas emissions, but they are rapidly getting greener with the evolution of digital technologies and the BIM process. Technological advancement is now a crucial role to play at the design and construction stages. Whilst BSE practice has sustainability and environmental design strategies in place, it is critical that these are built-upon with an endeavor to meet measurable design targets. The lack of clarity on such targets, and indeed questionable predictive modelling software, often hinders the formation of sustainable design solutions, whereby betterment in standardisation would avoid unintended negative consequences *(Appendix 16).*

5.2.3 TECHNOLOGY

5.2.3.1 MULTIDISCIPLINARY DIGITAL COLLABORATION

The key resource in engineering practice relates to its core competences, including the integration of multiple collaborative technology streams. By allowing market trends and new technologies to be discarded leads to professional obsolescence. This research reveals that engineering management must decide the *appropriate digital constructs* given time and money constraints, and indeed accuracy.

However, participants strongly advocate that the accuracy of digital design is often questionable, and that further validation and verification by management, who apply their experience to this explicit process as *rules-of-thumb and benchmarking.*

BSE management is in a position to pioneer design, and learn to leverage the comprehensive portfolios of digital technologies, or face being left behind. The Irish AEC industry is approaching digitalisation at different speeds and in different ways. Inevitably, there are initial barriers to adoption, such as high investment needs and a shortage of industry-wide proof of value. BSE practice is ramping-up their digital agenda to succeed in this challenging environment, and is set to reap the benefits from digitalisation. However, a technology-driven design practice requires the uprooting of entrenched behaviours and customs at all professional levels. Participants believe that management is in a position to lead and build teams that have the new digital competencies, establish the technological foundation, *disseminate digital skills across the practice*, whilst complementing digital capabilities through third parties to accelerate learning and compensate for any lack of internal resources *(Appendices 16 & 19).*

Although this practice-based research is qualitative in nature, the findings of this inquiry yield a strong correlation to the quantitative findings from the literature review, where barriers to BIM implementation principally relate to lack of client demand, lack of collaboration, expertise and training, limited time to upskill, selective projects, and more importantly, the absence of an established BIM framework in the Irish AEC industry *(Figure 26).*

5.2.3.2 BUILDING INFORMATION MODELLING

Undoubtedly, BIM is transforming the Irish AEC industry by changing the way multidisciplinary project teams collaborate to deliver significant efficiency. As familiarity and maturity increases in digital constructs, BIM is influencing a new generation of practitioners.

Unlike other industries, such as manufacturing, the Irish AEC industry is slow to adopt new technologies by digital transformation. Digitalisation can enable digital technology and processes on an *all-integrated* central platform of BIM. As its adoption increases, digital technologies enable practice to boost design and construction productivity, manage complexity, reduce project delays and cost overruns, and enhance safety and quality.

This research substantiates benefits to accrue at construction stage, where digitalisation will continue to increase efficiency through new forms of design by an increased front-loading approach at design stage *(Figure 57).*

Despite the huge potential to increasing productivity and overall efficiency, the adoption of BIM in BSE practice has been observed slower than expected. This research validates how there is now a greater reliance on digital constructs in practice, and in particular, the implementation of BIM, which not only systematises, but also simplifies the design process. The potential of digitisation in offering structured streamlined design and construction processes is vividly becoming a reality. The comparative evidence indicates how unnecessary design iterations can potentially be reduced by adopting the BIM process *(Figure 57).*

5.2.3.3 DIGITAL PRACTICE

Digitalisation is not solely about technologies, it is about practice, their processes and people, thus changing behaviours and providing a renewed purpose and identity aligned with these behaviours directly led by management can demonstrate its importance, and ensure that the means for success are provided. This research indicates that the most important practice investments will be in creating artificial intelligence and machine learning platforms to enable practice to become more capable and efficient *(Figure 57).*

The research also reveals that digital strategies should be launched by management with clear communication, showing their ambitions to generate an alliance in practice in response to the overall transformation with shared and transparent direction, capabilities, data and resources *(Figure 57)*. Participants believe that the time is now to implement a real digital strategy in BSE practice. BIM and the increasingly demanding client expectations make it compulsory to shift from a siloed mode to a real overall strategy. Defining a balanced transformation for practitioners will be key. It must be framed, planned, efficiently carried by management, thus allowing for creativity and flexibility. Participants also conclude that digital transformation is making worthwhile strides at present, with innovations steadily changing the way practice delivers for clients, and is accelerating out of necessity.

5.3 RESEARCH LIMITATION

Although the aim and objectives have been met through following a carefully planned methodology, this section outlines the unavoidable limitations of this research.

The management framework has been developed appropriately for its purpose to improve the BSE design process by the proficient convergence of people, processes and technology in practice, and moreover, clearly illustrate the findings of this inquiry. It is intentionally designed to not be exclusively ready for practice, but to probe thought into how this triangulated focus approach can optimise the relationship between people, processes and technology to the BSE design process. A process of testing and validation within industry has not taken place, and therefore, it is acknowledged that for the purpose of improving industry confidence in its adoption, pilot projects in which it is implemented would be required. This stage was not possible during this inquiry due to the restricted time and resource constraints. Such testing would enable a greater insight into further implementation guidance and improvements to emerge. This would require observation of this framework utilisation for the duration of a project lifecycle, and to evaluate its adaptability to subsequent projects. However, this is identified as the potential basis for further research *(Section 5.4).*

It is recognised that there are limitations in terms of conducting one case study, which may make it difficult to reach a generalising conclusion to the greater BSE industry in Ireland (Tellis, 1997). This was carefully considered during the contemplation of the most appropriate methodology to adopt. It was felt that the in-depth nature of case study research outweighs this limitation due to its ability to offer a greater insight into the phenomenon investigated. In reflection, this initial belief has been reaffirmed due to the case study approach enabling a much richer understanding of the problem than would be possible through alternative methods such as questionnaires and surveys. Accordingly, this allowed for an inductive research approach to be undertaken, thus facilitating a more robust and continuous theory building to take place.

The logic and power of this initial dataset lies in selecting experience-rich participants to illuminate the inherent inefficiencies at design stage, deficiencies at construction stage, and perceived dysfunction in BSE practice. However, this raises the question of whether this sample provides a true reflection of the views of the greater Irish BSE industry.

It remains true that sample sizes that are too small cannot adequately support claims of having achieved valid conclusions, and sample sizes that are too large do not permit the deep, naturalistic, and inductive analysis that defines qualitative inquiry. Determining an adequate sample size in this research was ultimately a matter of the researcher's judgment and experience in evaluating the quality of the information collected against the uses to which it was applied.

Structured, open-ended interview method was adopted for this inquiry, which required structured questions facilitating faster interviews that could be more easily analysed and compared. The interview questions were structured-open ended to systematically ask participants the same questions. Otherwise, the researcher would not be able to achieve data saturation, as it would be a constantly moving target (Guest, Bunce, & Johnson, 2006). Although this data was used to test various components of the theoretical framework, it is acknowledged that this interview method did not facilitate participant reflection, and thereby, the researcher did not challenge their thinking process. This is a weakness in the research data, whereby it was not possible to verify the results objectively against the scenarios stated by the respondents.

This qualitative inquiry required a high degree of reflection, whereby the researcher critically examined their role throughout the research process, and how their biases and decisions affected the data. In support of the triangulated data collection strategy, a self-reflective journal documented both personal and professional practice assumptions during the delivery of the case study project with the intention of clarifying these subjectivities *(Image 6).* The reflective journal writing also allowed the researcher to map their growing and changing understanding of their role as researcher, interviewer, and interpreter of the data generated from the interviews, and to record decisions made and theoretical justification for the decisions. Methodologically, this is an accepted practice from constructivist and interpretivist perspectives (MacNaughton, 2001). However, judgement based on the researcher's belief is often considered subjective in nature, and should be construed with caution.

Furthermore, the case study project engaged a traditional 5-stage public procurement method known as the Public Works Contract under the Capital Works Management Framework (PW-CF1) designed by the Employer. The BSE design process aligned to this form of contract is perceived as a limitation to the research, where design and construction processes differ in design-build contracts, thus potentially yielding different results.

Remarkably, there is no specific BSE design framework in Ireland. Consequently, Irish BSE practice has a tendency to adopt the BSRIA 8-stage design framework, which is principally intended to align with the RIBA 8-stage plan of work *(Figures 18 & 19).* This progression involves BSE management to intrinsically parallel the public (GCCC) and private (RIAI) contracts' 5-stage plan of work with the BSRIA 8-stage design framework, which is often contentious in the Irish AEC industry. By association, the design process in the practice-based case study project adhered to the public contract 5-stage plan of work *(Appendix 10).*

5.4 RESEARCH CONTRIBUTION

Despite practice research in engineering management being initiated sixty years ago, limited doctoral research has been conducted in BSE practice in Ireland. It is anticipated that the findings of this research will deliver value to practice by adapting a new management framework with practice core principles to improve the design process. This research draws upon critical perspectives, linking the theoretical and work experiences to understand and improve practice, removing avoidable risks during the construction stage, thus creating a new knowledge base.

Practice-based inquiry is an increasingly important field of research, one that has a significant contribution to make to decisions about knowledge and skill development of current and future management and practitioners. What has emerged from this inquiry is different to that presented in managerial literature, which tends to perceive practice as being exclusively made up of design, project management or technical problem solving. By contrast, this practice-based research presents a rather more complex portrait of practice, where interpersonal and technical constructs are inextricably interlink, which are rarely cited in contemporary literature, partly because the language of discourse is methodical, and can be difficult for outsiders to understand.

Creation and interpretation of new knowledge, through this scholarship, of a quality to satisfy peer review, extends to the leading edge of the BSE discipline, whereby management is well-positioned to improve the design process by adopting the practice principles through the systematic convergence of people, processed and technology, as identified in the developed management framework.

5.4.1 ACADEMIC KNOWLEDGE

This research is a means of advancing knowledge, it also serves as a disciplined and systematic procedure to assist industry peers in improving managerial effectiveness. Theory generated from this inquiry makes sense of managerial complexity that underlines practice, and elucidates efforts to improve the design process on building contracts in Ireland. In evidencing scholarly practice to create knowledge, the researcher stepped-back from the subjective immersion in events in their professional environs to dis-engage from the phenomena, which required a conscious role-shift from the tacit *know-how* to the explicit *know-about* by externalisation . This inquiry questioned conventional wisdom of management of the BSE design process, and deals rigorously with the evidence by the effective convergence of people, processes and technology.

5.4.2 PROFESSIONAL KNOWLEDGE

Understanding the idiosyncrasies in this research provides vital information to challenge and explore prevailing assumptions gained from a predominantly tacit body of knowledge in BSE practice. This research has identified activities that produce waste at design and construction stages, and their inherent impact in design practice *(Figures 38).* As the design process is becoming more multifaceted with the emergence of new disciplines in the built environment, new work practice is desirable by the implementation of a modern BSE management framework, which makes better use of management their practitioners, knowledge and technology. Today, competent management of the design process demands a balanced mandate with creative and technical *people* who understand its analytic *processes* and their empowerment to foster appropriate *technology.* This research concludes that the adaptation of this distinct managerial framework by BSE practices has the potential to enhance technical efficiency and operational effectiveness between design and business, thus sustaining a natural, social and built environment.

5.5 FUTURE RESEARCH

This inquiry thus endeavours to fulfil its aim and objectives *(Figure 5)* by contributing to the development of a BSE management framework *(Figure 58)* to improve the design process.

The progression of a theory-driven practice on the basis of a wider understanding of practice management could potentially bring about significant improvement in the design process, thus lessen deficiencies at construction stage, whilst lessening practice dysfunction.

This management framework is intentionally developed to not be exclusively ready for practice, but to probe thought into how a triangulated focus approach by optimising the relationship between people, processes and technology in practice. The research findings has unearthed a multitude of additional interest areas that require further research by refining and testing of interventions based on this framework.

A process of testing and validation of this framework within industry has not taken place, and therefore, it is acknowledged that for the purpose of improving industry confidence in its adoption, pilot projects in which it is implemented would be required. This stage was not possible during this inquiry due to the restricted time and resource constraints. Such testing would enable a greater insight into further implementation guidance and improvements to emerge. This would require observation of this framework utilisation for the duration of a project lifecycle, and to evaluate its adaptability to subsequent projects.

It was revealed that BSE practice often depends on MEP system providers for training on digital expertise, whereby unapproved technologies often adopted by the AEC industry. Accordingly, a more in-depth investigation of the dynamic interface between BSE practice and MEP system providers at design and construction stages would be required. This would enable greater insight into how mutual knowledge sharing of digital constructs is disseminated. Although investigated to a certain degree within the boundary of this research, the scope of this topic is substantial, which could easily form its own standalone study by utilising the findings and guidance outlined in this research as a basis.

The findings also reveal that BSE practice places greater priority of technical coordination at design stage for public projects than for private projects, where technical coordination is somewhat priortised at construction stage. As this process is viewed by the AEC industry as mutually exclusive regardless of the type of contract, further investigation would establish the impact in BSE practice, thus allowing a more informed conclusion into the most desirable management framework to be formulated for the respective contract.

This research affirms that BIM is the foundation of digital transformation in the Irish AEC industry. However, due to this state not currently being evident in all BSE practices at the time of the inquiry, further research is required to observe how BIM would impact a BSE management framework both positively and negatively. In addition, further research could lead to establishing the extent to whether other processes, such as improvements sustainability in design, could also be obtained through this framework.

***Progress is impossible without change; and those who cannot change their minds cannot change anything* – Bernard Shaw**

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APPENDICES

Appendix 1 *Publication*

Digital Engineering: a Case Study in an Irish Consultancy Practice

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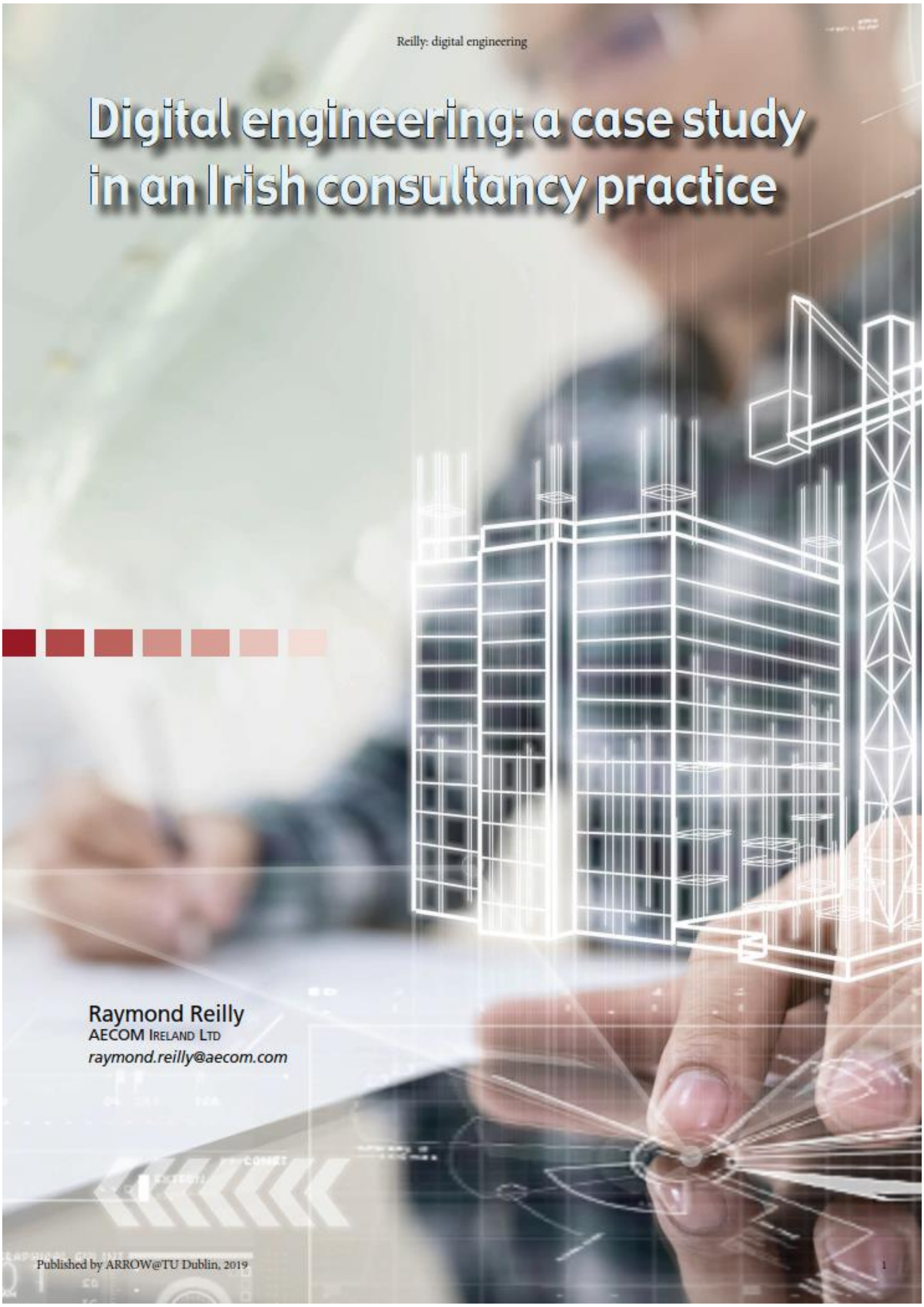

Reilly: digital engineering

Digital engineering: a case study in an Irish consultancy practice

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Abstract

The building services engineering (BSE) industry has wrestled with its productivity gap for many years and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design. Embracing digital technology provides smarter, faster, better and safer solutions. Scholarship in BSE consultancy practice is limited, and although this inquiry is a means of advancing knowledge, it also serves as a disciplined and systematic procedure by shedding a new light on design effectiveness in practice, thus improving the design process through digital engineering.

This paper outlines how digitalisation encapsulates people, processes and technology to improve the design process in Irish BSE practice, thus providing the basis for promoting a sustainable design process during and after design.

(This paper includes content submitted by the author as part of his Professional Doctorate in the Built Environment at the University of Salford).

Keywords

Digital Engineering, Building Information Modelling.

1. Introduction

What was once deemed the province of a craftsman, building services engineering (BSE) now demands the services of a body of highly-educated and specialist-trained professional engineers (Portman, 2014). Building services engineers are responsible for the design of the mechanical, electrical and public health (MEP) systems required for the safe, comfortable and environmentally-friendly operation of buildings (Miller, Vandome, & McBrewster, 2009). This multidisciplinary field of engineering essentially brings buildings and places to life. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process.

Thus far, research has identified that a large percentage of defects at construction stage arise through decisions or actions at the design stage; any unresolved design issues must be resolved at construction stage. Poor communication, lack of adequate documentation, deficient or missing input information, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision-making have been identified as the main problems at design stage. This inherent productivity gap leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage (Yongping, Chunyan, Pengfei, & Weiping, 2014). Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice. The small relative cost of the design process when compared to construction costs disguises its true importance for overall performance (Austin, Baldwin, & Newton, 1994).

BSE is a dynamic and complex design process due to its multi-disciplinary nature. It requires a high degree of technical competence to ensure that MEP systems are safely designed, legislatively compliant, and more importantly, technically coordinated with other team disciplines (Trevelyan, 2014). Success in BSE practice relies on the ultimate design deliverable being performed correctly. Moreover, BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra

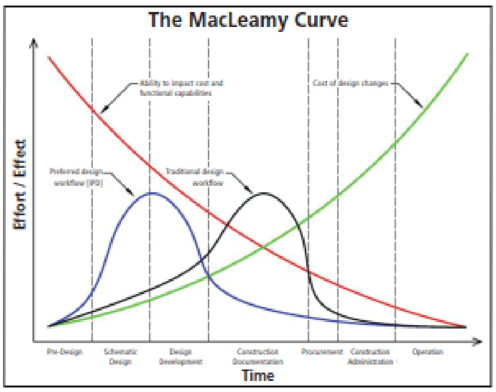

Figure 1: Design Workflow – The MacLeamy Curve (Walaseka & Barszczb, 2017).

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effort from practitioners with their openness in delivering quality design in the format of transferable digital information (Walaseka & Barszczb, 2017). Consequently, and according to the MacLeamy Curve (see Figure 1, p46), most of the practice workload and effort is encouragingly shifted towards the design stage.

The UK has led this adoption in response to its Government mandate, and is readily transferrable to the Irish construction industry (GCCC, 2017). The Irish government has recently committed to increasing the use of digital technology, and its statement of intent defines a Building Information Technology (BIM) Adoption Strategy to support the implementation of Government policy objectives in the procurement of public works projects, in their construction and in their maintenance upon completion (GCCC, 2017). BIM is gaining traction in Ireland at present, and it is essential that it receives the investment, focus and time initiated from a Government-led strategic framework to ensure it is successfully implemented (Engineers Ireland, 2019).

There is a real need to design buildings faster and cheaper in Ireland. This requires multidisciplinary practitioners to work together in a more concerted manner. A collaborative approach with BIM is proven to be more effective for successful projects, and can be further encouraged in the industry by redrafting the GCCC suite of contracts to include use of BIM processes and technologies (McAuley, Hore, & West, 2012). BIM implementation success lies in both cultural and technological change. It requires BSE practitioners to change outdated design practices, adversarial approaches, and to adopt new technologies and methodologies. Practitioners do not like change and without strong leadership and management, they are more likely to maintain the status quo of poor design practices (Montague, 2015).

This paper sets out the theoretical issues relating to the design process during the design and construction stages which required a well-disciplined literature review in order to synthesis its adaptability to BSE design practice. The theoretical components were then examined and tested from the findings on a practice-based case study on a modern grandstand building at the Curragh Racecourse, County Kildare (see Image 1), completed in May 2019 and with a construction value of €87 milion.

It is intended that this research will draw upon critical perspectives, linking the theoretical and work experiences to understand and suggestively improve practice, removing avoidable risks during the construction stage, thus creating a new knowledge base (Rigg & Trehan, 2008). It is also recognised that lessons drawn from one case study are limited, and therefore practitioners can extrapolate design process improvements from their own experience. Notwithstanding this, the researcher has established strong parameters and set clear research objectives which is critical in case study design (Yin, 1994).

Figure 2: Sources of Theoretical and Conceptual Frameworks (Trafford & Leshem, 2012).

1.1 Theory and Practice Test

Linking theory and empirical research through interactions from reading, reflection and assumptions has enabled the researcher to develop new theory (see Figure 2).

This empirical research of engineering design practice at both design and construction stages is set in the context of *people*, *processes* and *technology* (PPT) in order to synthesise its theoretical adaptability to BSE practice (see Figure 3, next page). The reason for this triangulated focus is that successful project implementation requires an approach that optimises the relationship between PPT. Ensuring that the BSE team consists of people with relevant education, skills and experience who are committed to conducting staged processes throughout the project life and supported by suitable digital technologies is imperative for effective engineering practice. BSE is not simply a design-based process but a complex integration of explicit and tacit knowledge of both technical and managerial practitioners nearing a successful installation at construction stage (Sheppard, Colby, Macatangay, & Sullivan, 2006).

Image 1: Practice-based Case Study Project – Grandstand at the Curragh Racecourse (Reilly, 2019).

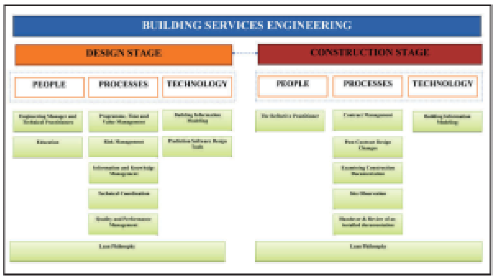

Figure 3: Primary Scope of Literature Review.

The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates. The theory of diffusion of innovation not only validates this fact, but also demonstrates that practitioners who are more willing to adopt new innovations have different characteristics when compared to those who adopt innovation later (Walaseka & Barszczb, 2017). The chasm occurs at the transition between the early adopters and the early majority. It is suggested that once 16% adoption of any innovation is reached, media strategy is changed from one based on scarcity, to one based on social proof in order to accelerate through the chasm to the tipping point. The tipping point is the point at which the mainstream begins to adopt the innovation (Maloney, 2010) (see Figure 4).

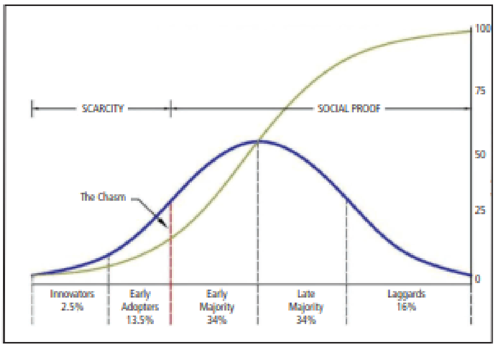

Figure 4: Rogers' Law of Diffusion of Innovation (Maloney, 2010).

2. Digital Technology

Engineering design practices' key resources are related to their core competences, including integrating multiple streams of technologies. By allowing market trends and new technologies to be disregarded leads to professional obsolescence (Engineers Ireland, 2016). The BSE design process and, by extension, the construction process is somewhat aided by the use of computer models which create virtual buildings and simulate the performance of mechanical and electrical systems (Portman, 2014). Undoubtedly, BIM is transforming the construction industry by changing the way multidisciplinary project teams collaborate at every stage of the project cycle to deliver significant efficiency and cost-saving benefits. As familiarity and maturity increase across the globe, BIM is set to influence a new generation of practitioners (British Standards Institute, 2019). Thus far, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify (Li, *et al*, 2014).

BSE-related technology changes faster than that in any other part of a building or place. The development of BSE software design packages is intended to improve the efficiencies of MEP systems, but new digital demands are arising from the technological change taking place in the activities of building occupants. While the BSE design process is also aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources, the best modelling programs cannot account for the unpredictable nature of occupants (Portman, 2014).

2.1 Digitalisation

Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation. Undoubtedly, the wider use of technology, digital processes, automation and higher-skilled practitioners contribute greatly to the economic, social and environmental future (EUBIM, 2017). The use of digital technology has, until recently, largely been confined to the pre-construction stage. Indeed, the construction and operational phases are still somewhat reliant on paper outputs from the digital platforms used at the design stage. This is because, until relatively recently, the technology had not developed sufficiently to facilitate the complex supply chain that contributes to a construction project. BIM is now evolving to provide a means of extending the digital reach into the construction and operation stages (GCCC, 2017).

It is no secret that the Irish construction industry is changing. The impact of technological advancements in recent years has been nothing short of transformative. Clients are demanding higher quality, greater reliability, faster delivery and the higher safety standards. Recent advances in technology have brought new ways to optimise project delivery, increase productivity and create efficiencies throughout the design and construction stages (AECOM, 2018). By rethinking the way digital technology plays a role in the BSE practice, it is imperative to establish radical new solutions, thus transforming project delivery and unlocking the full power of the BSE consultancy offer to clients. By connecting with market-leading digital expertise, practitioners can leverage the scale to deliver innovative, differentiated solutions to clients, boost performance and ultimately grow business.

The National BIM Council (NBC) of Ireland's recent endeavour to roadmap digitalisation of the Irish construction industry advocates more productive ways of working that improve competitiveness. This roadmap is divided into four key pillars – leadership, standards, education and training, and procurement. Remarkably, the Irish government has not yet afforded adequate leadership in diffusing BIM, and has failed to provide online supports or reviews of the suitability or provisions made for developing public construction contracts. However, the National Standards Authority of Ireland (NSAI) has developed a BIM certification program aligned with the publication of IS EN 19650: Part 2, providing an internationally-recognised standard for BIM. Moreover, third-level and professional institutes are perceived as entities for upskilling prospective and

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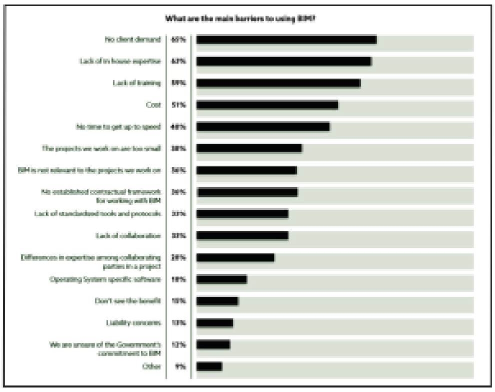

Figure 5: Main barriers to BIM implementation (NBS, 2019).

current practitioners, respectively (McAuley, Hore, & West, 2019).

While Ireland has recently shown a steady increase in some aspects of its BIM maturity, barriers to its implementation are inherent (Figure 5). BIM necessitates significant change to workflows, practices and procedures. It requires investment of knowledge in BIM standards and protocols, training in new software platforms, and financial investment to access these digital tools (NBS, 2019).

2.1.1 Digital Engineering

Using existing technologies, as well as developing new digital solutions through the use of artificial intelligence, facilitates BSE practitioners in designing systems that better meet clients' needs during all stages of the project lifecycle. This research suggests that practitioners who adopt digital tools to develop an innovative new approach to BSE design will dramatically improve the efficiency and quality of the design process.

The traditional design process, where detail is added to design components throughout, sees components designed from scratch for each project, creating re-work as more precision is built into the design. Digital libraries allow the creation, storage and reuse of proven and at-the-ready design components on multiple projects from the outset, dramatically reducing the time needed to design systems. The use of digital libraries continue to create efficiencies into the construction stage (GBC, 2019). Standardised components, specifications and tutorials stored within the model help speed up construction and procurement, potentially creating efficiency improvements of up to 20% on a typical project. This leads to reduced design and construction cost, improved design and construction quality, faster design and construction, and design practice efficiencies. By repeating the use of a standardised digital toolkit, design time is reduced, and the inherent prescriptive approach helps reduce design rework (BIM Today, 2019).

2.1.2 Digitally Transforming BSE Design

Digitally transforming the BSE design process has the potential to support practitioners and help clients make better-informed decisions by using automated knowledge-sharing and generative design techniques that provide multiple design options earlier in the design process. Providing detailed 3-d plantroom information with scheduling and cost data at scheme design stage, rather than at detailed design, means cost plans can be tested earlier and realistic financial models can be developed from the start, minimising risk and the program and cost impacts of design changes (Sacks, Eastman, Teicholz, & Lee, 2018).

Practitioners can then produce highly-detailed, construction-ready, designs that will improve technical co-ordination with the wider design team, reducing contractor design, requests for information schedules, change requests and shorten construction programme. Transforming the BSE design process permits better decision-making with more information, increases the productivity of the entire design team, improves cost certainty and reduces programme costs, thus reducing BSE contract times at construction stage (Schober, 2016).

Digital design tools have the potential to reap 20% savings in consultancy practices (Agarwal, Chandrasekaran, & Sridhar, 2016). *Automatic load calculations* help achieve significant time savings and create agility in responding to design changes by starting with the automation of standard rule-of-thumb calculations and leading to fully-automated dynamic simulations.

Automatic plantroom and riser-sizing tools facilitate the design of plantrooms and risers in 3-d. Creating a full set of plant and area schedules speedily allows for greater detail at earlier design stages, reducing costs and helping clients review options to choose the best solution for their building (AECOM, 2019). Standardisation of content and automated design detailing processes help produce more detailed and complete information without spending additional time on projects, improving design information and reducing issues during construction. Recent advances in digital technology have brought new ways to optimise project delivery, increase productivity and create efficiencies throughout the design and construction stages (Parsons, Mischke, & Barbosa, 2017). BSE practitioners must transform the way they use technology and data to deliver more efficient and valuable solutions to clients (Lawlor, 2017).

Adopting a digital workflow strategy, BSE teams supporting projects from inception to completion ensure that clients will benefit from digital best practice, workflow and governance throughout. Through a digital-healthy-start, practitioners can mobilise digital skills early on a project, ensuring the best available technologies are in place from the start. This strategy improves productivity in design between 2% and 10% by facilitating greater multidisciplinary coordination, reducing design-stage rework, reducing project costs due to reduced site clashes and issues, and improved stakeholder engagement (Byrne, 2018).

Implementing digital design reviews to improve coordination on large complex projects, and to facilitate collaboration between design teams and project stakeholders, is essential. Digital reviews bring together BIM from different design disciplines to facilitate clash detection and interdisciplinary coordination. The use of a combined model involving all stakeholders to conduct regular reviews helps identify issues early and increases program certainty.

The use of virtual and augmented reality technologies further enhances the design review process, immersing practitioners in full-scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction. It engages all project stakeholders in the design review/development process, and the visualisation of the design (Behzadi, 2016). Including visualisation and immersive technology is helping the project team to visualise projects like never before, and are transforming the design process. Blurring the lines between the physical and digital world, virtual reality (VR) and augmented reality (AR) are helping practitioners visualise projects (Fossett, 2016). Whether supporting public consultation, or engaging stakeholders in the design process, immersive technology is helping clients make better-informed decisions, with confidence (Leeuwen, Hermans, Jylhä, Quanjer, & Nijman, 2018).

Immersive technology is bringing digital models to life, allowing all stakeholders from architects, engineers and contractors to owners and end-users, to intuitively interact with a design in real time, wherever they are (Heydarian, *et al.*, 2015). Clients can now interact with their final project throughout the design process, transforming how they engage with designs. On complex projects with multiple stakeholders, clients can see intricate areas of the design and discuss alternative design solutions. It boasts a platform for more efficient design with real-time updates to the model from all stakeholders, clash avoidance and enhanced client review process, and seamless working across teams and locations. In addition, more efficient construction is instigated by heightened value engineering and constructability in design, operations and maintenance benefits with boosted input from owners, operators and end-users (Bolton, 2018).

Practitioners need to actively embrace digital technologies, thus accelerating digital transformation by expanding their existing digital solutions and nurturing new ideas (European Commission, 2016). Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare. Practice challenges will include accelerating technological change, driving multi-industry disruption leading to winners and losers, new industries replacing older ones, and practitioners' expectations around work and how/where they want to work.

2.1.3 Building Information Modelling in BSE Practice

In an effort to remedy the issue of stagnant labour productivity in the Irish construction industry, BIM was proposed in the late 1980s as a new solution for streamlining the design and delivery process of construction projects, a digital representation of a building meant to serve all project disciplines as a repository of all relevant data throughout the project's lifecycle. Despite the huge potential for increasing productivity as well as the overall efficiency, the adoption of BIM throughout the construction industry has been observed to be slower than expected (Walaseka & Barszczb, 2017). Fortunately, the Irish BSE industry is small and agile enough to evolve quickly by adapting new technologies to existing expertise, and to learn lessons during this adaption while becoming world class in design (Montague, 2015).

Recent technological and digital developments currently offer an integral BIM 3-dimensional software for BSE design (Szeląg, Szewczak, & Brzyski, 2017) which are demonstrating to be a game-changer in Irish consultancy practice. In particular, MagiCAD was developed as a

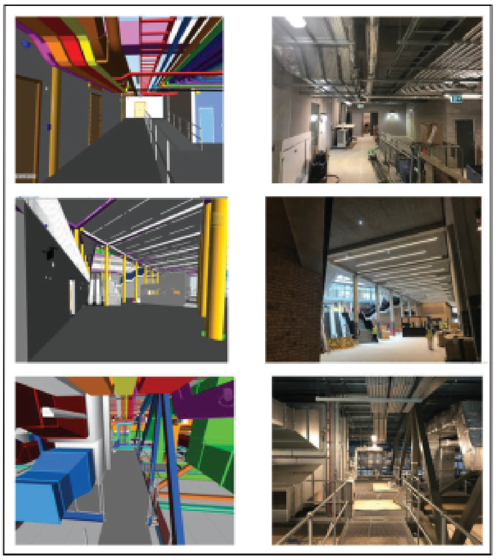

Image 2: Synchronized MEP BIM model applying MagiCAD (Case Study Project).

powerful design tool to save time with more user-friendly, flexible, intelligent, and parametrical user environment (MagiCAD, 2016), and was successfully implemented at the design stage on the case study project. It enabled the MEP design using an extensive product model database, featuring real product families from leading manufacturers across the globe. Each model within the database came complete with accurate dimensions and comprehensive technical data allowing for accurate calculations, advancing the working environment to create a more streamlined workflow that removed monotonous tasks, thus reducing time in the design process. It also provided collision control, and enabled easier and more efficient technical coordination with other disciplines' intentions during the design process, most notably, architecture and structural engineering. Image 2 demonstrates the accuracy of design by applying MagiCAD. The principle benefits of using this digital engineering technology during implementation of the Grandstand included plant space allocation, scenario planning, early and accurate visualisations, automatic maintenance of consistency in design, enhanced building performance and quality, checks against design intent, accurate and consistent drawing sets, earlier collaboration of multipledesign disciplines, synchronised design and construction planning, discovering errors before construction, and lifecycle benefits regarding operating costs of the building. However, the implementation in MagiCAD in Irish BSE practice is in its infancy, and its practicality and effectiveness are difficult to quantify at this stage.

3. Research Findings and Discussion

A great deal of qualitative material comes from talking with people, whether it is through formal interviews or casual conversations (Woods, 2006). The interview method used for this inquiry offered

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the researcher access to BSE practitioner experience at design and construction stages. The questions were primarily informed from findings in the literature review, and presented to the participants in the context of the case study, allowing them reasonable opportunity to present phenomena in their own terms (MacDonald, 2012). A sample of 15-BSE practitioners with varying degrees of experience were strategically chosen to participate. There are many practical recommendations regarding a sample size with the most usual recommendation of 12-20 interviews (Onwuegbuzie & Leech, 2007).

3.1 People

Most interview participants agreed that the BSE design process is dynamic and complex due to its multidisciplinary nature, and requires technical competence and collaboration to ensure that MEP systems are designed effectively ensuring a good quality building within a reasonable cost programme. The participants also acknowledged that the design process lasts from project inception to completion, which infers that the design process does not specifically conclude once the design is fully detailed at pre-construction stage, thus contravening theorists design principles. The concept that inferior BSE design is a consequence of poor design coordination incurring significant programme delays and costs at construction stage (Portman, 2014) not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering constructs. This phenomenon infers that such deficiencies lead to *fire-fighting* and *tension* between disciplines, thus concurring with current literature.

The postgraduate experience of each participant ranged from five years to 15 years. All participants agreed that the Irish educational system does not adequately prepare graduates for digital engineering practice. Albeit technical theory underpins successful project design, it is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a *2-d world*. Most worryingly, it is believed that graduate engineers are unaware of the *real* implication of *adjusting* detailed design and its inherent impact on other design disciplines, most notably, architectural and structural engineering.

All BSE participants acknowledge working in silos albeit *cognisant* of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage. It is inferred that there is dependence on *good* contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process, suggesting that improvements in multidisciplinary team coordination at design stage could potentially reduce implications during installation.

BSE practitioners are cognisant of the so-called *half-life* of technical knowledge in engineering practice. While most practitioners are normally keen to evade this *outdated* status, many do not share this vested interest, highlighting that *you can take the horse to water, but you can't make it drink*. Participants also disclose that project time demands negates sufficient time for adequate formal training to enhanced their digital skillset. Moreover, there is a decisive aspiration from practitioners to implement new design tool technologies albeit time constraints continue to limit research in testing the feasibility and accuracy of inherent digital engineering tools.

It is expected that the recent endeavour by the National BIM Council (NBC) of Ireland to roadmap digitalisation of the Irish Architecture Engineering and Construction (AEC) sector will pave the way for greater productivity in digital practice by enhancing leadership, education and training among its practitioners.

3.2 Processes

The introduction of digital specialisms such as BIM, thermal modelling (TM) and computational fluid dynamics (CFD) has in fact initiated *silo* working environments in BSE practice. Participants expressed concerns that current practice is veering towards each practitioner being a *one-for-all* BSE practitioner, which in their view is not practical in modern practice, and consequently, introduces dissonance between designers.

Design coordination problems are known for their ill-definedness and complexities which result as a lack of information (Park & Lee, 2017). The design coordination process is intended to allow each discipline to compare their respective materials that are intended for given space in a building to ensure they will not conflict physically or impair the installation and maintenance of subsequent systems. BSE participants argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. This structure ensures that the right information is available when required in the right format (Portman, 2014). All participants tend to *poach* as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time. Consequently, it is imperative that up-to-date industry standards and specifications are managed and easily accessible by practitioners. BSE participants are confident that the adoption of ISO 19650 (Parts 1& 2) will facilitates an excellent common data environment in terms of in-house filing and project templates at both project design and delivery stages.

3.3 Technology

Engineering design is often too complex to carry out manually due to the significant number of variables. The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

Participants insinuate that CFD software *does not reflect real-world*, and is dependent on accurate input parameters which are often *difficult to define* to simulate a realistic model. This research intimates that thermal modelling software provides a *good guidance*, but similarly, there is reliance on many variables at the outset to achieve an exact simulation. Inherent variables such *as people behaviour, building operation, weather conditions and building construction materials* are imperative in achieving accurate results.

This research affirms that adopting integrative technologies to MEP design projects is essential to enable stakeholders to instantly collaborate on an integrated design platform. Design practitioners that depend on 2-d drawings will be at a professional disadvantage by their inability to fully visualise the building and relevant angle views due to the limitations of drawings. Participants explain that the transition from 2-d to 3-d is a *painful* one. Its adoption demands greater time to coordinate the 3-d model at design stage which incurs higher costs to the design team.

Participants also reveal that although working in a collaborative environment, sharing the BIM model among other disciplines is not a straightforward activity. The BSE team requires other discipline designs to be complete, that is, architecture and structural engineering, prior to their design input. Participants readily admit another major challenge relating to BIM modelling representation; detailed design of 3-d models must be well advanced prior to presenting resultant 2-d drawings. This is a significant drawback for BSE practitioners who aim to produce work-in-progress drawings during the design process. Moreover, MagiCAD is offering BSE practitioners with an illustrative mechanical and electrical engineering design software. The participants believe that its concept is *brilliant* for elements of design, and advocate that its adoption demands intensive training in order to reap the rewards.

4. Conclusion

The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence.

The theoretical path in this research ultimately focused on understanding the empirical system in practice by applying data collection from interviews to test the various components of the BSE design process. Theory generated from this case study makes sense of the complex dichotomy between the design and construction stages that underpins BSE practice in the context of people, processes and technology, thus elucidating efforts to improve the current design process through digital engineering. This triangulated focus ensures that the BSE team consists of people with relevant education, skills and experience who are committed to conducting staged processes throughout the project life, and more importantly, supported by suitable digital technologies to sustain a modern engineering practice.

Notwithstanding the failure of the Irish government to lead and move with the digital evolution, the recent strategic initiative by the National BIM Council (NBC) of Ireland has the potential to overcome the key barriers to digitalisation in the AEC sector. The full implementation of this strategy would provide a more productive way of working in the BSE industry by enhancing leadership, standardising the adoption of a digital platform (BIM), and providing education and training to current and prospective practitioners.

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Appendix 2 *Ethical approval*

Ethical approval was required as the research design involved human subjects working in their professional environment. As research findings could potentially be offensive and may bring the researcher's practice into disrepute, an application was submitted for approval to the School of the Built Environment Research Ethics Committee.

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building
University of Salford
Manchester
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

6 December 2018

Raymond Reilly
Dear Raymond,

RE: ETHICS APPLICATION STR1819-04 - Developing a framework to improve the building services engineering design process; a case study of engineering management in Irish consultancy practice.

Based on the information you provided, I am pleased to inform you that your application STR1819-04 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

APHigham.

Dr Anthony Higham
Chair of the Science & Technology Research Ethics Panel

Appendix 3 *Doctoral workshop programme*

NR	LOCATION	DATE	FACILATORS
1	University of Salford (Media City)	13 Oct 2013	*Dr Paul Chynowth, John Hudson*
2	University of Salford (Media City)	30 Nov 2013	*Dr Paul Chynowth, John Hudson*
3	University of Salford (Media City)	25 Jan 2014	*Dr Paul Chynowth, John Hudson*
4	University of Salford (Media City)	08 Mar 2014	*Dr Paul Chynowth, John Hudson*
5	University of Salford (Media City)	12 May 2014	*Dr Paul Chynowth, John Hudson*
6	University of Salford (Media City) – *Joint*	20 Jun 2014	*Dr Paul Chynowth, John Hudson*
7	University of Salford (Media City)	21 Jun 2014	*Dr Paul Chynowth, John Hudson*
8	University of Salford (Media City)	12 Jul 2014	*Dr Paul Chynowth, John Hudson*
9	University of Salford (Media City)	04 Oct 2014	*Dr Paul Chynowth, Dr Jim Kempton*
10	University of Salford (Media City)	01 Nov 2014	*Dr Paul Chynowth, Dr Jim Kempton*
11	University of Salford (Media City)	07 Feb 2015	*Dr Paul Chynowth, Dr Jim Kempton*
12	Anglia Ruskin University	19 Jun 2015	*Dr Paul Chynowth, Dr Jim Kempton*
13	Anglia Ruskin University – *Joint*	20 Jun 2015	*Dr Paul Chynowth, Dr Jim Kempton*
14	University of Salford (Media City)	24 Oct 2015	*Dr Rod Gameson, Dr Julian Holder, Prof. Vian Ahmed*
15	University of Salford (Media City)	13 Feb 2016	*Dr Rod Gameson, Dr Julian Holder, Prof. Vian Ahmed*
16	University of Salford (Media City) - *Joint*	18Jun 2016	*Dr Rod Gameson, Dr Julian Holder, Prof. Vian Ahmed*
17	University of Salford (Media City)	22 Oct 2016	*Dr Rod Gameson, Dr Julian Holder, Prof. Vian Ahmed*
18	University of Salford (Media City)	11 Feb 2017	*Dr Rod Gameson, Dr Julian Holder, Dr Mark Shelbourn*
19	University of Salford (Media City) - *Joint*	10 Jun 2017	*Dr Rod Gameson, Dr Julian Holder, Dr Mark Shelbourn*
20	University of Salford (Media City)	11Nov 2017	*Dr Mark Shelbourn, Dr Lucy Montague*
21	University of Salford (Media City)	17 Feb 2018	*Dr Mark Shelbourn*
22	University of Salford (Media City) - Joint	16 June2018	*Dr Rod Gameson, Dr Peter Mann, Dr Stan Lester*
23	University of Salford (Media City)	10 Nov 2018	*Dr Mark Shelbourn, Mr Derek Hales*

NR	LOCATION	DATE	FACILATORS
24	University of Salford (Media City)	16 Feb 2019	*Dr Mark Shelbourn, Mr Derek Hales*
25	University of Salford (Media City) – *Joint*	15 Jun 2019	*Dr Paul Chynowth, Dr Peter Mann, Mr Derek Hales*
26	University of Salford (Media City)	09 Nov 2019	*Dr Mark Shelbourn, Mr Derek Hales*
27	University of Salford (Media City)	15 Feb 2020	*Dr Derek Hales, Dr Peter Mann*

Appendix 4 *Professional practice and academic research*

RESEARCH	DATE	DETAILS
PROFESSIONAL PRACTICE		
Lean Construction Ireland Conference	30 Mar 2016	*Sustaining Excellence Through Innovation*
Industry Field Research	25 May 2016	*Lean Philosophy Underpins Growth*
AECOM	26/27 Mar 2016	*Managing Projects*
Uptime Institute	19/20/21 May 2016	*Building Services Design Management*
Engineers Ireland	21 Nov 2016	*Design Thinking in Engineering Design and Projects*
AECOM	27 Jan 2017	*Project Management; Preparing for Success*
Engineers Ireland	14 Feb 2017	*Expert Witness Training for Engineers*
The BIM Conference	29 Apr 2017	*Building Information Modelling in Construction Projects*
Lean Construction Ireland Conference	02 Oct 2018	*Lean Innovation – Inspiring our Future in Construction*
Trinity College Dublin	29 Nov 2019	*Guest Lecturer – Engineering Management*
Lean Construction Ireland Conference	03 Oct 2019	*Lean Innovation – Inspiring our Future in Construction*
Project Ireland 2040	26 May 2020	*Its role in recovering from the Covid-19 Crisis*
CIF Digital Construction Virtual Summit	07 Jul 2020	*How disruption will re-shape the Construction Industry*
Building Information Modelling	20 Sep 2020	*BIM Application Tutorials*
ACADEMIC		
Trinity College Dublin	27 Feb 2016	*Achieving Lean Through Cultural Change*
Design Management Institute	21 Jul 2016	*Lean Startup, Design Thinking & Open Innovation*
Lean Construction Institute	03 Oct 2016	*Building People, Transforming Culture.*
Trinity College Dublin	15 Nov 2016	*Reflections on an Engineering and Industrial Journey*
Design Management Institute	08 Mar 2017	*From SMEs to Large Corporates: Building Design*
Design Management Institute	12 April 2017	*Creative Leadership: Achieving Design Excellence*

RESEARCH	DATE	DETAILS
Design Management Institute	23 Aug 2018	*Strategic Design: 8 Essential Practices*
Design Management Institute	18 May 2018	*Design & Innovation: Delivering Value*
Lean Construction Institute	14 June2018	*Transforming Design and Construction*
Design Management Institute	18 Jul 2018	*A Design-Led Approach to Innovation*
Design Management Institute	10 Oct 2018	*The Insider's Guide to Innovation*
Lean Construction Institute	21 Dec 2018	*Lean Design Management Strategies*
Design Management Institute	13 Mar 2019	*How Artifical Intelligence Will Transform Design*
Lean Construction Institute	28 Aug 2019	*Lean – BIM (Digital Design | Construct | Operate*
Journal of Sustainable Design and Applied Research (SDAR)	08 Nov 2019	*Digital Engineering; a case study Irish BSE Practice*

Appendix 5 *Supervisor liason record*

ATTENDEES	DATE	CONSULTATION
Prof. Carl Abbott	9th May 2014	*University of Salford*
	11th July 2014	*University of Salford*
	13th November 2014	*University of Salford*
Dr Paul Chynoweth (Temporary)	3rd June 2015	*Video Conference*
Dr Rod Gameson	10th June 2015	*Video Conference*
	24th July 2015	*Video Conference*
	25th September 2015	*Video Conference*
	24th October 2015	*University of Salford*
	12th February 2016	*University of Salford (Media City)*
	8th June 2016	*Video Conference*
	18th June 2016	*University of Salford (Media City)*
	26th August 2016	*Video Conference*
	10th October 2016	*Video Conference*
	30th January 2017	*Video Conference*
	26th April 2017	*Video Conference*
	24th May 2017	*Video Conference*
	20th July 2017	*University of Salford*
	11th November 2017	*University of Salford (Media City)*
	15th December 2017	*Video Conference*
	11th February 2018	*University of Salford (Media City)*
	20thApril 2018	*Video Conference*
	16th June 2018	*Video Conference*
	13th August 2018	*University of Salford (Media City)*
	3rd October 2018	*Telephone Conference*
Dr Stephen Allen	23rd October 2018	*Video Conference*
	9th November 2018	*University of Salford*
	21st December 2018	*Video Conference*
	15th January 2019	*University of Salford*
	22nd February 2019	*Video Conference*
	1st April 2019	*Video Conference*
	29th April 2019	*University of Salford*
	30th April 2019	*University of Salford*
	15th June 2019	*Video Conference*
	21st July 2019	*Video Conference*
	11th September 2019	*Video Conference*

ATTENDEES	DATE	CONSULTATION
	7th November 2019	*University of Salford*
	14th February 2020	*University of Salford*
	18th March 2020	*Video Conference*
	17th July 2020	*Video Conference*

Note that both the supervisor and student have also corresponded in detailed on issues relating to the learning agreement, ethical approval, general research progress and interim assessment report.

Appendix 6 *Learning agreement*

POSTGRADUATE RESEARCH LEARNING AGREEMENT

PGR LEARNING AGREEMENT

Student's Family Name:	Reilly	**Student / Roll Number:**	@00380558
Student's Given Name(s):	Raymond Noel	**Date of Registration:**	31st January 2022

1. Approach to Research:

The researcher, with the direction of Dr Stephen Allen, will adopt an in-depth study for a professional doctorate by investigating building services engineering management during the design stage and its impact during the construction. It is envisaged that a close working relationship will be required between the student and the supervisor, Dr Allen, particularly, in the demands of the theoretical and practical aspects of the study. Basically, it is envisaged that the partnership between student and supervisor will be one involving mutual respect, constructive and on-going exchange of criticism and ideas.

The study drives its importance from the effective role that engineering management play in design consultancy practice. As far as the researcher is aware, this study is the first of its kind in Ireland, and therefore, it is hoped that this study will provide some useful insights, implications and recommendations for organisations alike.

Contribution to knowledge is expected to comprise the following;

i) Construct a new light on existing engineering management theory through critical literature reviews and interaction with BSE practitioners,

ii) Appraise the design and construction stages in the context of people, processes and technology,

iii) Articulate inefficiencies at design stage, define deficiencies at construction stage, and consequent dysfunction in design practice,

iv) Development of a management framework to improve the BSE design process,

v) Draw conclusions of the relevance of engineering management techniques to improve the design process, and

vi) Lessen professional dissonance between BSE practice and specialist contractors.

Oct 2016 v2
http://www.pg.salford.ac.uk/page/progression_forms

Research Topic; *Engineering management*

Research Problem; *The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.*

Research Question; *Can developments in building services engineering management improve the design process?*

Research Title; *Development of a management framework to improve the building services engineering design process; a case study of engineering management in an Irish consultancy practice*

Research Aim (the 'what'); *The principle aim of this research is to develop a management framework to improve the BSE design process by the proficient convergence of people, processes and technology in practice.*

Research Objectives *(the 'how') with respective research methods are as follows;*

i)

NR	OBJECTIVE	METHOD
I	Synthesis of BSE management theory	Conduct a literature review of design management and project management to provide a theoretical overview of engineering management
II	Develop a theoretical management framework	Conduct a literature review to exemplify how engineering management can improve the BSE design process by the efficient convergence of people, processes and technology, and its dichotomy at design and construction stages
III	Examine and test components of the theoretical management framework with empirical data to devise a revised framework	Conduct a cross-sectional instrumental case study of a practice-based project to gain insight to real engineering management at both design and construction stages. Empirical data principally sourced and analysed from interviews with 15-BSE professionals, and supplemented by case study project documentation, and the researcher's reflective journal
IV	Test the validity of the revised framework with empirical data	Test components of the revised framework with empirical data sourced and analysed from interviews with 5-seasoned professionals in the Irish BSE industry
V	Extrapolate a conclusive BSE management framework	The interpretivism paradigm is adopted to put data analysis in context, where the researcher has relied heavily on interviewing, observation and analysis of existing knowledge

As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms. The researcher will conduct a manual qualitative analysis to provide succinct reckoning of interview references to codes that are specific aspects of engineering practice. This method will provide personal first-hand experience of the researched, and thus, heighten an understanding of it.
The researcher affirms that the research findings will be derived principally from the interviews, whereas data collection from both the case study documentation and the researcher's self-reflective journal will play a supporting role in interpreting the data.

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METHODS USED TO ACHIEVE OBJECTIVES

1. PRINCIPAL ONLINE SEARCH FACILITATORS

Research Gate
https://www.researchgate.net/application.Login.html

University of Salford
http://www.salford.ac.uk/library

Construction Information Service (CIS)

Trinity College Dublin (Stella Library &Wiley Online Library)
https://www.tcd.ie/Library/

Academia.edu
www.academia.edu

Emerald Insight
www.emeraldinsight.com

Construction Industry Research and information Association (CIRIA)
www.ciria.org

Journal of Engineering Education
https://www.asee.org/papers-and-publications/publications/jee

Journal of Educational Research
https://www.journals.elsevier.com/international-journal-of-educational-research

Journal of Sustainable Design and Applied Research (SDAR)
http://arrow.dit.ie/sdar/

Engineering Management Research (EMR)
http://www.ccsenet.org/journal/index.php/emr/article/view/67911/36825

2. PRINCIPAL BOOK REVIEW

Stepping Stones to Achieving Your Doctorate;
Prof. Vernon Trafford http://vernontrafford.com/

Research Method for Managers
J.Gill and P. Johnson

Qualitative Inquiry and Research Design
Choosing among Five Traditions
J.W. Creswell

Building Services Design Management
After Design During Construction
J.Portman

The Reflective Practitioner
D. Schon

Advanced Research Methods in the Built Environment
A. Knight and L. Ruddock

The Making of an Expert Engineer
J. Trevelyan

Quality Management for Building Design
T. Cornick

Measuring Quality in Planning
M. Carmona & L. Sieh

Cost and Value Management in Projects
R. Venkataraman & J. Pinto

Knowledge Management in Theory and Practice
K. Dalkir

Digital Delivery; Transforming the Design Process
D. Sinclair

3. BUSINESS MANAGEMENT FACILITORS

Association of Consulting Engineers of Ireland (ACEI)
http://www.acei.ie

Engineers Ireland (EI)
https://www.engineersireland.ie

Chartered Institute of Building Services Engineers (CIBSE)
https://www.cibseireland.org/

Irish Centre for Business Excellence
http://icbe.ie/index.php/best-practice-visits/

Management Works
http://www.managementworks.ie/about

Enterprise Ireland
https://www.enterprise-ireland.com/en/funding.../Lean-Transform.html

Design Management Institute
https://dmi.site-ym.com/general/register_member_type.asp

Online Theses
EthOS (E-theses Online Services)
http://ethos.bl.uk/SearchResults.do

Lean Construction Ireland
http://lciconference.com/

2. Roles and Responsibilities of Postgraduate Researcher and Supervisor(s):

Having read the Code of Practice for the Conduct of Postgraduate Research Degree Programmes, I understand the duties and responsibilities included in it. I understand that my supervisor, Dr Stephen Allen, will guide and advise on aspects of research design and validity.

The topic is not ethically sensitive, but care will be given to any work involving interviews, correspondence by email and the use of unpublished grey literature and archive resources in terms of property and personality rights. Where interviews or other primary data collection involving human subjects are to be carried out, ethical approval will be sought from the university Research Governance and Ethics Subcommittee.

3. Consultation and reviews:

Dr Stephen Allen and I have agreed in principle to discuss my research progress on a monthly basis via skype and in person when possible. I will be receptive to comments and criticisms of my supervisors and ready to change my views, but also critically challenge my supervisor's advice.

A formal meeting will be held every month at which the supervisor will be present in order to discuss progress. The researcher will provide a progress report at the beginning of each meeting and keep a record of what has been discussed in his research journal. Additional contact will be made between the researcher and supervisors by telephone and email as and when necessary. Any feedback requested from the supervisors by the postgraduate will be provided, if it is deemed to be required.

3.1 Interim Assessment completed in July 2017

- Literature review with outcomes *(key factors, theoretical framework)* with outline methodology developed.

3.2 Internal Evaluation completed in May 2019

- Methodology/methods developed and data collected with substantial analysis complete,
- Data collection complete (validation phase) with preliminary results and conclusion,
- Final write-up and formal submission in January 2022.

4. Topic Specific Considerations:

The research includes a very wide body of literature in *engineering management* which requires a well-disciplined literature review in order to obtain a highly focused research by synthesising its theoretical adaptability within the realm of building services engineering consultancy practice.

Engineering management research will principally focus on;

i) the design and construction stage in the context of people, processes and technology *(Refer to Figure 1)*, and

ii) the design-construction interface.

There are few reliable reports of research in engineering practice. Very few observations have been reported on the actual work performed by management, practitioners and technologists. Indeed, numerous processes in other disciplines such as *design and project management* have been extensively studied yet *building services engineering management* has hardly received any attention.

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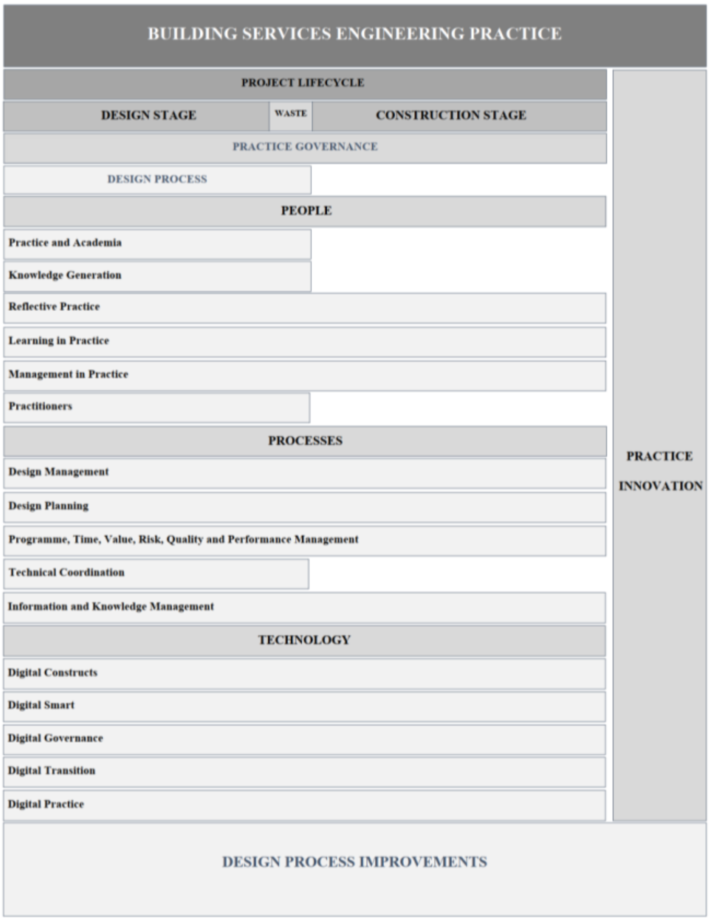

Figure 1 *Theoretical framework for BSE management*

Thusfar, this research has identified that a large percentage of deficiencies at construction stage arise through decisions or actions in the design process, no comprehensive study has been carried out previously in an Irish building services engineering practice to gauge this correlation. The design process is found to be a major source of problems for the subsequent project stages, even to the extent of undermining systematic management. Decisions made during the design process are multi-dimensional made by project team members combining factors ranging from the highly subjective to the perfectly objective. Building services engineering management is in a position to influence and reduce deficiencies that arise during construction. This research initiative presents an opportunity to improve the design process, thus elevating the importance of removing avoidable risks during the construction stage.

It is here that the theoretical framework has evolved, providing a theoretical overview of the proposed research and order within the research process; *Refer to Figure 1*. This framework will be empirically tested and validated, as necessary. A case study in building services engineering practice will be presented taking cognisance of triangulated data collection.

Ethical Approval

Ethical approval was required as the research design involved human subjects working in their professional environment. As research findings could potentially be offensive and may bring the researcher's practice into disrepute, an application was approved by the School of the Built Environment Research Ethics Committee.

5. Research Support Requirements:

In order to develop the research methodologies, methods needed to gather the data, understand current issues related to the research, and develop the needed skills to become a truly independent researcher, it is envisaged that a number of research related courses and doctoral workshops will be attended.

5.1 Specific facilities or resources you will be accessing? Please detail below

Resources/facilities	Yes	No	Details
Laboratory facilities	☐	X	N/A
Room use (e.g. for rehearsals, interviews or focus groups)	☐	X	N/A
Specific hardware (particular computers, media editing facilities, printers, art-related materials)	☐	X	N/A
Specific software	☐	x	N/A
Other	☐	X	N/A

6. Personal, Professional and Career Development

6.1 Short term priorities:

- Research Data/Information Management

- Familiarisation with manually interview data analysis

6.2 Specific training events/programmes that you aim to participate in

- University of Salford - Wordscope (2017/18/19)

6.3 Longer term priorities: skills that you hope to have developed by the end of your research degree

- Independent researcher

6.4. *Guest Lecturer – Building Services Engineering Design*

- Trinity College Dublin (November 2018)

6.5. *Publish paper in the Journal of Sustainable Design and Applied Research (November 2019)*

- Digital Engineering; a case study in an Irish Building Services Engineering Consultancy Practice

7. Relationship with Collaborating organisation (if applicable):

Industry peers *(managers, engineers and technicians)* in building services engineering practice.

8. Change of Supervisor (if applicable):

Action plan to mitigate any negative impact: N/A

This Learning Agreement is made on : 31st January 2022 between the above named Postgraduate Researcher and the University of Salford

Signatures:

Supervisor: **Dr Stephen Allen** Stephen Allen

% of supervision: **100%**

For and on behalf of the University of Salford

Co Supervisor: **Prof. William Swan**

Personal Tutor: **Dr Paul Chynoweth**

Postgraduate Researcher: **Raymond Reilly** Raymond Reilly

Date **31st January 2022**

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APPENDIX 1 – ETHICAL CHECKLIST

Please Note: the purpose of this checklist is to highlight ethical considerations. You will also need to apply for Ethics Approval via http://www.salford.ac.uk/ethics

Checklist Form for Learning Agreement **for use by postgraduate research students to accompany the Learning Agreement**	Office use only **Ref No:**

Who should complete this form?

This form should be completed by all students studying for a postgraduate research degree. This checklist forms part of the Learning Agreement, which must be completed within 3 months of commencing the study, and must be updated annually.

Ethics approval must be obtained by all students prior to starting research with human subjects, animals or human tissue. The student must discuss the content of their checklist form with their supervisory team. A final copy of the checklist form will then be agreed and the student and the main supervisor will sign it off. The student must attach a copy of the completed form to their Learning Agreement, which must be submitted to the Research Support Officer within 3 months of commencing the study and updated annually.

This form must be completed electronically; the sections can be expanded to the size required.

SECTION A – to be completed by ALL students

Family Name of student:	Reilly
Given Name(s) of student:	Raymond Noel
Student Roll No:	@00380558
Programme of study:	Doctor of the Built Environment
School:	School of the Built Environment
Supervisor:	Dr Stephen Allen

1. Title of proposed research project

Development of a management framework to improve the building services engineering design process; a case study of engineering management in an Irish consultancy practice.

2. Research Summary

The original contribution will be made by drawing attention to a new light on existing engineering management theory through critical inquiry, assessing the design and construction stages in the context of people, processes and technology, identifying inefficiencies at design stage, deficiencies at construction stage, thus dysfunction in design practice, and to draw conclusions of the relevance of engineering management techniques to improve the design process.

3. Project objectives

Key Research Objectives (the 'how') are as follows;

i) Synthesis of BSE management theory

ii) Develop a theoretical management framework

iii) Examine and test components of the theoretical management framework with empirical data to devise a revised framework

iv) Test the validity of the revised framework with empirical data, and

v) Extrapolate a conclusive BSE management framework

4. Summary of Research Methodology.

The research methodology adopted for this inquiry is guided by the researcher's philosophical beliefs based on ontological, epistemogical and methodological assumptions.

The somewhat traditional *research onion* will be adopted for this inquiry which provides an effective progression through which a research methodology is designed. Indeed, its usefulness lies in its adaptability for practically any research methodology creating a series of stages under which the different methods of data collection can be understood, and illustrates the steps by which a methodological study can be described.

This inquiry will investigate engineering management at design and construction stages which favour a strong qualitative research approach. The review of current theory laid the groundwork for cross-sectional instrumental case study, that is:

- Accomplish something other than understand a situation,
- Insight into an issue and refine a theory,
- The case is of second interest playing a supportive role in understanding the project life-cycle in the context of design and construction stages,
- A snapshot of the project life-cycle from related disciplines. Unlike longitudinal studies that would look the project life cycle over an extended period, cross-sectional studies are used to describe what is happening at the present moment.

This practice-based case study will be presented taking cognisance of triangulated data collection as follows;

i) ***Interviews*** – Structured, open-ended

Structured, open-ended interviews will be adopted for this research, and involves asking the participants structured questions facilitating faster interviews that can be more easily analysed and compared. The researcher will conduct a manual qualitative analysis to provide succinct reckoning of interview references to codes that are specific aspects of engineering consultancy practice. This method will provide personal first-hand experience of the researched, and thus, heighten an understanding of it, and is expected to make a worthwhile contribution to the design-construction interface in practice *(Figure 1).*

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT PRACTICE
BUILDING SERVICES ENGINEERING PRACTICE				
1	MEP Engineering Director	Master in Engineering	28	4
2	Mechanical Engineering Lead	Bachelor of Science	12	4
3	Senior Mechanical Engineer	Master in Engineering	8	3
4	Project Mechanical Engineer	Bachelor of Science	5	4
5	Electrical Engineering Lead	Bachelor of Science	16	6
6	Senior Electrical Engineer	Bachelor of Science	12	2
7	Project Electrical Engineer	Bachelor of Science	5	5
PROGRAMME AND COST CONTROL PRACTICE				
8	PCC Practice Lead	Bachelor of Science	28	28
9	Lead Programme & Cost Consultant	Bachelor of Science	25	25
10	Project Programme & Cost Consultant	Master of Science	9	9
MECHANICAL AND ELECTRICAL ENGINEERING CONTRACTOR				
11	MEP Coordinator	Bachelor of Science	25	10
12	Electrical Engineering Contractor Lead	Bachelor of Science	32	20
13	Mechanical Engineering Contractor Lead	Bachelor of Science	15	10
14	Cost Control Manager (Electrical)	Bachelor of Science	9	5
15	Cost Control Manager (Mechanical)	Bachelor of Science	11	7

Figure 1 *Interview Participants (Case Study)*

ii) Document Analysis

To enhance the reliability of data collection, documentation relating to the practice-based case study project will be procured from both the engineering design practice and contractor firms to get a clear picture of how BSE management fared over time (Figure 2).

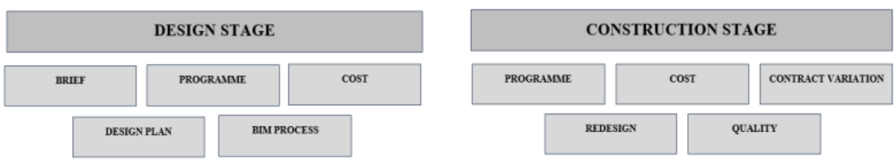

Figure 2 *Document Analysis*

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iii) Self-reflective Journal

In support of triangulated data collection, a *self-reflective journal* will be used by the researcher to document both personal and professional practice assumptions with the intention of clarifying self-belief systems and subjectivities.

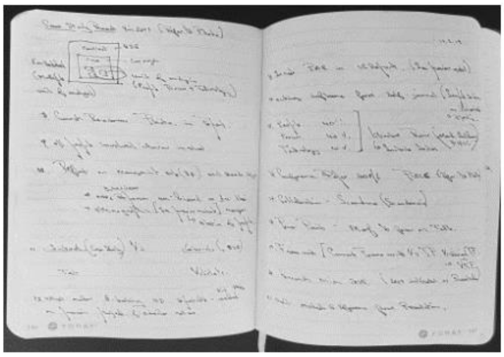

Figure 3 *Researcher's self-reflective journal*

Testing the validity of the *revised* theoretical framework

ii) ***Interviews***

- Experience rich professionals in 5 nr Irish BSE consultancy practices (Figure 4)

This research design while being the means advancing knowledge, also serves as a disciplined and systematic procedure to assist the researcher in improving managerial effectiveness in practice, thus improving efficiency at design stage. This research process conceptualises the practice-based issues and the logical sequence that connects the empirical data to the research aim and ultimately to its conclusions. To establish reliability and validity in this doctoral inquiry, the methodological challenge demands well defined reasoned conceptions.

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT ENGINEERING PRACTICE
EXTERNAL - Building Services Engineering Consultants				
1	Managing Director (MEP)	*Master of Science*	28	28
2	Managing Director (MEP)	*Bachelor of Science*	25	15
3	Technical Director (MEP)	*Master of Science*	17	5
4	Technical Director (MEP)	*Bachelor of Science*	19	5
5	Technical Director (MEP)	*Master of Science*	14	2

Figure 4 *Interview Participants (Validation)*

SECTION B

USE OF HUMAN/ANIMAL SUBJECTS/TISSUE (incl. volunteers, questionnaires etc)

5. **The following checklist is to help students and supervisors easily identify projects which *may be* designated as Type 3. [Type 3 projects are those where there is a significant ethical dimension]. Students whose projects are identified as potential Type 3 will be expected to submit a full case separately for Research Ethics Approval.**

One or more 'Yes' answers in this section indicates that the project is very likely to be designated as Type 3.

RISK OF HARM AND RELATED ISSUES		
Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	☐ Yes	☑ No
Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants?	☐ Yes	☑ No
Is there any possible risk to the researcher (e.g. working alone with participants, interviewing in secluded or dangerous places)?	☐ Yes	☑ No
Will participants undergo sound exposure beyond the Lower Action Level of the Physical Agents Directive?	☐ Yes	☑ No
Does the project require the use of hazardous substances?	☐ Yes	☑ No
Is the use of radiation (if applicable) over and above what would normally be expected (for example) in diagnostic imaging?	☐ Yes	☑ No
Does your project involve work with human/animal tissue?	☐ Yes	☑ No
Will blood or tissue samples be obtained from participants?	☐ Yes	☑ No
VULNERABLE GROUPS AND FINANCIAL INDUCEMENTS		
Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐ Yes	☑ No
Do participants fall into any of the following special groups? *(tick all that apply)*		
• Children (under 18 years of age);	☐ Yes	☑ No
• People with learning difficulties or communication difficulties;	☐ Yes	☑ No
• People who speak a different language;	☐ Yes	☑ No
• Patients or clinical populations and/or their carers;	☐ Yes	☑ No
• Pregnant women or research on conception or contraception;	☐ Yes	☑ No
• People in custody or any form of detention;	☐ Yes	☑ No
• People engaged in illegal activities (e.g. drug-taking)	☐ Yes	☑ No
OTHER		
Are there any other potential significant ethical issues not covered above? If Yes, please give details:	☐ Yes	☑ No

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In electronically signing this form I certify that the above information is, to the best of my knowledge, accurate and correct. I understand the need to ensure I undertake my research in a manner that reflects good principles of ethical research practice.

Signed by Student:

Date: 31st January 2022

In electronically signing this form I confirm that I have read and agreed the contents and I am satisfied that the project can only proceed subject to approval by the University of Salford Ethics Approval Committee.

Signed by Main Supervisor:

Date: 31st January 2022

NB: The ethical and efficient conduct of research by students is the direct responsibility of the main supervisor.

Initial assessment by supervisor:

This research project is deemed to be:

☐ **Type 1** Routine project work. No Ethics approval required.

☑ **Type 2** Routine project work involving human/non-human subjects/tissue where ethical issues have been considered and appropriately addressed.

☐ **Type 3** Project where there is a significant ethical dimension.

Appendix 7 *Practice approval for the interview method*

Researcher's Address

September 2018

Researcher Employer's Address

Dear ***Researcher's Employer Team Lead***

I am a student on the Doctorate in the Built Environment programme at the University of Salford. As part of my course I am conducting a research study titled: ***Developing a framework to improve the building services engineering design process; a case study of engineering management in Irish consultancy practice.***

Prior to undertaking the study I need your agreement/consent to approach 9nr participants within your organisation to take part in the study. Please refer to overleaf for selected personnel. I have adapted a qualitative inquiry and as such I will be conducting interviews with key technical and programme & cost control disciplines mentioned.

I can assure you that I will make every effort to ensure the study does not disrupt the working environment in any way and any data collected will remain confidential. I am applying ethical approval for the study from the University of Salford, School of the Built Environment.

If you have any concerns about my research, please contact my supervisor; **x**

Yours Sincerely,

X

Doctorate in the Built Environment Candidate

Organisation Consent: **X**

Signed:

Position:

Date: September 2018

Appendix 8 *Interview participant information sheet*

Science & Technology

Ethical Approval Panel for Taught Programmes

Overview of the Participant Information sheet ***(Case Study & Validation Interviews)***

The Researcher is writing a dissertation for a doctorate degree in the built environment. He is conducting a case study investigation of engineering management at design and construction stages at his consultancy practice. The research is intended to develop a framework to improve the building services engineering design process.

As part of the research design, he has chosen *interviews* as his key research method. The interview questions have been informed by a detailed literature review relating to engineering management in the context of people, processes and technology in engineering practice.

Study Title
Developing a framework to improve the building services engineering design process; a case study of engineering management in an Irish consultancy practice.

Invitation
I would like to invite you to take part in a research study. I have chosen to use interviews as my primary research method. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or if you would like more information. Please take time to decide whether or not to take part.

What is the purpose of the study?

It is acknowledged that deficiencies at construction stage arise through actions at design stage, but no comprehensive study in an Irish building services engineering practice has been conducted to gauge this correlation. It is suggested that 75% of the problems encountered at construction stage are generated at the design stage. The impact of such deficiencies in design practices is rarely understood in terms of cost and programme, but it is estimated that an additional 40-50% of the total work hours of a project may be required to rectify deficiencies at construction stage.

This inquiry drives its importance from the effective role that engineering managers play in design, and as far as the researcher is aware, this study is the first of its kind in Ireland, and therefore, it is hoped that this study will provide some useful insights, implications and recommendations to consultancy practices alike.

Why have I been invited?
Building services engineering involves multidisciplinary teamwork which often generates problems when design is shared between several designer disciplines that do not always share the same knowledge and often have contradicting objectives designing a project.

As respective discipline leads in Mechanical, Electrical, Building Information Modelling, and Programme and Cost Control , you have been chosen as ideal candidates.

Do I have to take part?
Participating in this research is entirely voluntary. I will describe the study and go through the information sheet, which I will give to you prior to the interview. I will then ask you to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without giving a reason.

What will happen to me if I take part?
You will participate in an interview in a designated meeting room in your practice. The interview time slot is estimated at 45-minutes. The interview process will involve a closed fixed-response method, that is, all participants will respond to identical pre-determined questions. The interview will be recorded using a dictaphone (Olympus VN-741PC). The content of the interview will be transcribed, analysed and documented in my dissertation thereafter. You should note that my research findings will be anonymous.

What will I have to do?
I have prepared interview questions with a view to understanding each practitioner experience during the design and construction process in building engineering practice. You are expected to respond to these questions in an honest and professional manner.

What are the possible disadvantages and risks of taking part?
I do not envisage any risks or inconvenience to you arising from your participation in this research.

What are the possible benefits of taking part?
It is often said that reflection is unlikely to occur where professionals automatically apply routine work practices – *nothing grows in a comfort zone*. The interview will pave the way for each participant to reflect on their respective practices. I cannot promise the research will help you, but its findings may help to increase your understanding of engineering management in a building services engineering consultancy practice.

What if there is a problem?
If you have a concern about any aspect of this research, please discuss with the researcher.

If you still remain unhappy and wish to complain formally, you can do this through sending a letter setting out the details of your complaint to the researcher's Head of School.

Will my taking part in the study be kept confidential?

Your input to the research will remain confidential and will be safeguarded during and after the research is conducted. The data collected will be handled, processed, stored and destructed in accordance with the Caldicott principles and Data Protection Act 1998.

Please note that the data collected will be used as a practical test to discuss and compare theoretical constructs findings (literature review) in the context of people, process and technology at both design and construction stages.

All information which is collected during the course of the research will be kept strictly confidential, and any information about you which leaves the university will have your name and address removed so that you cannot be recognised.

Respect for persons demands that interview participants enter into this research voluntarily and with good information about the research aim. The selection of participants has been justly for reasons directly related to the research problem being investigated. In order to undertake research in a manner that reflects good principles of ethical research practice, the researcher will adhere to the University of Salford's Code of Practice for the Conduct of Postgraduate Research Degree Programmes 2017/2018. Furthermore, as a chartered member of both Engineers Ireland and the Association of Consulting Engineers of Ireland, the researcher is also bound by their respective Code of Ethics.

What will happen if I don't carry on with the study?
If you withdraw from the study I will destroy all your identifiable tape recorded interviews, but I will need to use the data collected up to your withdrawal.

What will happen to the results of the research study?
The results of the research will be made available to each participant on request. Although publishable, the research findings will not be identified in any report/publication unless I have been given your consent in writing.

Who is organising or sponsoring the research?
The research is being sponsored by researcher's employer.

Will my taking part in the study be kept confidential?

Your input to the research will remain confidential and will be safeguarded during and after the research is conducted. The data collected will be handled, processed, stored and destructed to match the Cadicott principles and Data Protection Act 1998.

Please note that the data collected will be used as a practical test to discuss and compare theoretical constructs findings (literature review) in the context of the following;

- differences in understanding between inherent building services engineering disciplines

- identify the main barriers to project success during the design process

- discuss how project success can be achieved by developing strategies for people, process and technology

- recommend a work design to enable building services engineering professionals to work efficiently and effectively

All information which is collected during the course of the research will be kept strictly confidential, and any information about you which leaves the university will have your name and address removed so that you cannot be recognised.

What will happen if I don't carry on with the study?
If you withdraw from the study I will destroy all your identifiable tape recorded interviews, but I will need to use the data collected up to your withdrawal.

What will happen to the results of the research study?
The results of the research will be made available to each participant on request. Although publishable, the research findings will not be identified in any report/publication unless I have been given your consent in writing.

Who is organising or sponsoring the research?
The research is being sponsored by AECOM Ltd.

Further information and contact details:

Raymond Reilly	(m)	087 2997477	(e)	reillyr3@tcd.ie
Dr Rod Gameson	(t)	0044 161 295 4621	(e)	R.Gameson@salford.ac.uk

Appendix 9 *Interview participant consent forms*

University of Salford MANCHESTER

Science & Technology

Ethical Approval Panel for Taught Programmes
Example Research Participant Consent Form

Title of Project:	**Developing a framework to improve the building services engineering design process; a case study of engineering management in Irish consultancy practice.**
Ref No:	**Doctorate in the Built Environment** **(Practice-based Research Project)**

Name of Researcher: Raymond Reilly

(Delete as appropriate)

➢ I confirm that I have read and understood the information sheet for the above study and what my contribution will be.	**Yes**	**No**
➢ I have been given the opportunity to ask questions (face to face, via telephone and e-mail)	**Yes**	**No**
➢ I agree to take part in the interview	**Yes**	**No**
➢ I agree to participate in recorded interviews	**Yes**	**No**
➢ I agree to digital images being taken during the research exercises	**Yes**	**No**
➢ I understand that my participation is voluntary and that I can withdraw from the research at any time **without giving any reason**	**Yes**	**No**
➢ **I agree to take part in the above study**	**Yes**	**No**

Name of participant: **Interview Participant Nr**

Signature

Date:

Name of researcher taking consent: **x**

Researcher's e-mail address: **x**

If you have any concerns about this research that have not been addressed by the researcher, please contact the researcher's supervisor via the contact details below:

Supervisor's name **x**

Supervisor's email address: **x**

Appendix 10 *Case study plan of work*

STAGES 1 TO 5 INCLUSIVE

1. Obtain the design team leader's instruction for commencement of each stage.

2. Provide full mechanical and electrical engineering services in accordance with the Capital Works Management Framework (CWMF) procedures, as amended by this document.

3. Allocate competent and qualified personnel at the commencement for the duration of the project and ensure continuity of service between personnel.

4. Provide a full mechanical and electrical engineering service throughout all stages of the project to include civil works, building works and building fit-out.

5. Communicate and cooperate as required in the design process and with other consultants at all stages.

6. Comply with these service requirements and any authorised client/design team leader's instruction.

7. Throughout the project take the design team leader's instructions and implement these in relation to costs within the project. Prepare regular cost reports at agreed intervals and respond promptly to all client/design team leader requests for information relating to the project.

8. Attend meetings as instructed by the design team leader. Visit proposed site, examine site reports and generally report on all cost aspects of the development.

9. Assist in the preparation of the project programmes, including programmes for procurement and construction. Comment on programmes prepared and submitted by contractors. Agree programme for the delivery of the services and ensure that all reports and other documentation are delivered within the agreed programme.

10. Work closely with the quantity surveyor regarding the cost implications of mechanical and services during all project stages and to adopt an energy efficient design approach.

11. Carry out regular cost checks as the design is developed and advise as necessary to allow the design team to design to the agreed budget.

12. Observe the implementation of the client's sustainability and environmental objectives for the project. Take full account of the principles of conservation and international best practice.

13. Demonstrate to the client that as high a rating as possible be achieved through design, having regard to the nature of the building and best conservation practices.

14. Consulting local authorities on matters of principle in connection with the mechanical and electrical design of the works. Advise the design team and the client of the requirements of various utilities.

15. Communicate and cooperate with the design team leader and other consultants to ensure that documentation is provided in a suitable format and to the required level of detail.

16. Assist the design team leader in the preparation of comprehensive reports for client approval at the end of each stage.

STAGE 1: FEASIBILITY STUDY - PRELIMINARY REPORT

1. Contribute to the development and preparation of project brief in consultation with the design team lead.

2. In consultation with the design team lead, contribute to the detailed project programme immediately on appointment setting out how the project will be delivered within the required time period or by the required delivery date. This detailed project programme shall be maintained and updated in agreement with the client. Amendments to the programme should always seek to ensure that the project will be delivered within the required time period or by the required delivery date, while maintaining an adequate float for unforeseen events.

3. Contribute to the preparation of a full and complete statement of the client's functional, aesthetic and operational requirements for the project.

4. Advise and assist the design team lead in developing the project budget.

5. Contribute to preliminary cost estimates and outline cost plan for the project and assessment against the agreed budget.

6. Contribute to design risk assessments.

7. Contribute to the examination and preparation of alternative design solutions, adjustments and design revisions as required to meet the project brief and budget.

8. Carry out design review with reference to functionality, efficiency, sustainability, commercial liability, economy, whole life costs and suitability for financing, sale or lease, as may be required.

9. Advise the design team lead on the necessity for studies, reviews, research, investigations, surveys, tests or the like and coordinate the implementation of these and associated reports. Advise the design team lead in relation to advance works requirements where applicable.

10. Site appraisal and report: Carry out feasibility studies and prepare all necessary drawings for site appraisal showing all relevant information both existing and proposed new works.

11. Advise the design team lead on work breakdown structure and procurement strategy for the project, having due regard to the project brief, the capabilities of the client organisation, characteristics of the project (urgency, complexity, size), market conditions and the Client's requirements on risk allocation.

12. Contribute to project status review, design review, risk assessment, value management and cost check interventions, arrange associated workshops at appropriate intervals and initiate and monitor any consequential or remedial action necessary.

13. Contribute to site investigation process, site surveys and tests, examination of availability of public utilities and associated reports.

14. Assist in preparation of Stage 1 report for client review.

15. Notify milestone completion to design team leader and submit invoice for payment.

STAGE 2A: OUTLINE SCHEME DESIGN & PLANNING

1. Contribute to the scheme design and general design specification in accordance with the project brief.

2. Comply with design production programmes set by the design team lead.

3. Contribute to pre-planning, fire safety and any other necessary statutory or regulatory consultation as required.

4. Contribute to consultation and liaison with adjoining owners or interests, including third parties and stakeholders.

5. Contribute to a project specific sustainability and energy use strategy, and satisfies the client's requirements in a cost effective manner.

6. Consult with design team lead and examine options for thermal performance of building, particularly with regard to sustainable energy, including, where appropriate, a report on fuel options.

7. Prepare outline sketch design incorporating mechanical and electrical services into floor plans for the building illustrating how it is proposed to provide the accommodation set out in the project brief. The plans shall be accompanied by sections and elevations indicating the floor and roof levels and the general character and massing of the proposed building. A number of options may need to be examined to satisfy the client requirements, cost limits and planning, fire safety, disability access and health and safety requirements. The design must be reconciled with the brief requirements. Submit outline sketch design to the client.

8. Participate with the design team and other consultants in value engineering and life cycle costing exercises.

9. Participate in value engineering, cost efficiency and buildability assessments and advise on any necessary corrective action required to meet budget.

10. In consultation with the quantity surveyor provide all necessary building services engineering cost advice, investigation and support to the design team including examination of alternative designs, adjustments and revisions to meet the project brief and budget. Prepare costings for design options or alternative designs as required.

11. Carry out whole life cost assessments as required in consultation with the quantity surveyor.

12. In consultation with the quantity surveyor assess and control the possible costs, benefits, programme and technical implications of proposed design changes.

13. Carry out design review with reference to functionality, efficiency, sustainability, commercial viability, economy, whole life costs and suitability for financing, sale or lease, as may be required.

14. Advise the design team lead on the preparation of the planning and fire certificate application, disabled access certificate i.e. requirements for boiler houses, plant rooms, flues, services compounds or any other.

15. Advise the PSDP, as appropriate, in the preparation of the preliminary health and safety plan.

16. Prepare preliminary building services drawings and report. a number of options may need to be examined to satisfy the client needs, cost limits and planning, fire safety and disability access requirements. The design must be reconciled with the requirements of the project brief.

17. Prepare a preliminary specification indicating the materials, plant and equipment, and any specialist methods of construction or of any particulars with regard to maintenance and replacement of plant proposed to be adopted.

18. Prepare developed sketch design for mechanical and electrical engineering elements.

19. Advise design team lead as required in the preparation of fire certificate submission, including preparation of layout drawings and outline specification.

20. Arrange for a detailed review with the design team lead of the mechanical and electrical drawings and specifications, and formally confirm that they have been prepared in accordance with the project brief and that they are consistent with architectural drawings.

21. Revise as necessary the mechanical and electrical engineering documentation following the above detailed review with the design team lead and the client and submit revisions for approval.

22. A reasonably detailed specification of materials, and method of construction, shall be prepared.

23. Carry out examination and preparation of alternative design solutions, adjustments and design revisions as required to meet the project brief and budget.

24. In consultation with the quantity surveyor assess and control the possible costs, benefits, programme and technical implications of proposed design changes.

25. Provide information to the quantity surveyor and other consultants to enable quantification for preparation of cost estimates and cost plan.

26. Provide information to the quantity surveyor and other consultants to undertake and prepare value engineering exercises.

27. Prepare design risk assessments throughout the duration of the design development stage.

28. Update risk register.

29. Contribute to project status review, design review, risk assessment, value management and cost check interventions, attend associated workshops at appropriate intervals and in advance of applications for statutory approvals and take any consequential or corrective action indicated.

30. Contribute to cost estimate update and cost check in advance of planning and fire safety submissions.

31. Contribute to report on the scheme design addressing all aspects of the developed design in an integrated manner in relation to the project brief, end user requirements and budget.

32. Assist in the planning application, ensure compliance with the planning scheme to include all associated technical reports as required. Respond where required to requests, planning appeal process, if applicable, and assessment and compliance with planning conditions.

33. Contribute to the risk management strategy and risk.

34. Assist in the preparation of a procurement strategy for the project with the design team lead.

35. Assist in preparation of Stage 2a report for client review.

36. Notify milestone completion to design team leader and submit invoice for payment.

STAGE 2B: DETAILED DESIGN

1. Develop detailed design and general design specification in accordance with the project brief, planning and fire safety certificate approvals, and the requirements of the CWMF Public Works Contracts.

2. Comply with design production programmes by the design team to meet the agreed programme.

3. Attend to consultation and liaison with adjoining owners or interests, as required.

4. Contribute to project status review, design review, risk identification and management, value management and cost check interventions, arrange associated workshops at appropriate intervals and initiate in coordination with the design team lead.

5. Assist in the preparation of a detailed coordinated design programme for this stage, fully addressing all necessary resource inputs, deliverables and approvals, with input from the other consultants.

6. Assist in the preparation of a fire safety certificate application and provide all necessary associated drawings and specifications for the purposes of the application.

7. Carry out all necessary consultation and assist in the preparation of an application for disability access certificate including all necessary associated drawings and specifications for the purposes of the application.

8. Integrate into the design of the project any requirements of specialist consultants or contractors (note – by contractors this term for the purposes of this document is to include for subcontractors or specialist contractors).

9. In consultation with the quantity surveyor provide all necessary building services engineering cost advice, investigation and support to the design team including examination of alternative designs, adjustments and revisions to meet the project brief and budget. prepare costings for design options or alternative designs as required.

10. Carry out whole life cost assessments as required in consultation with the quantity surveyor.

11. In consultation with the quantity surveyor assess and control the possible costs, benefits, programme and technical implications of proposed design changes.

12. Advise on the need for any specialist contractors and associated cost factors, carry out and/ or coordinate detailed design for specialist works.

13. Carry out detailed design coordination in relation to integration of building services engineering installation together with detailed examination and resolution of interfaces with building fabric, structure, fittings, fit-out and equipment.

14. Coordinate the provision of necessary design and specification information to the quantity surveyor for the developed cost plan report to be updated as required from time to time and reviewed against the agreed budget, and for further regular cost checks to be carried out up to tender.

15. Prepare detailed specification documentation for the works, including samples, testing, prototype and QA procedures, with particular regard to sustainability, quality and standards required.

16. Prepare design and building maintenance risk assessment, and provide all necessary building services engineering technical and design information to the PSDP for incorporation into the pre-tender health & safety plan.

17. Advise on the need for any specialists and associated cost factors.

18. Assist the design team lead in the preparation of a report on the detailed design addressing all aspects of the developed design in an integrated manner in relation to the project brief, key stakeholder requirements, accommodation and budget. assist in a full design briefing to the client.

19. Conduct design review with reference to functionality, efficiency, sustainability, commercial viability, economy, whole life costs as may be required.

20. Produce comprehensive works requirements documents, all coordinated detailed design drawings and specifications for the works.

21. Prepare and complete works' contract production information including detailed specialists' design for tender documentation, tender drawings, specifications and forms of tender to provide a fully documented proposal for tendering and subsequent tender evaluation in accordance with the CWMF Public Works contracts.

22. Contribute to the risk management strategy and risk register for incorporation in the tender documents including identified risks, risks transferred to contractor, and retained/ managed risks.

23. Arrange for pre-tender developed cost plan update and cost check in advance of issue of tender documentation.

24. Assist in preparation of Stage 2B report for client review.

25. Notify milestone completion to design team leader and submit invoice for payment.

STAGE 3: TENDER ACTION, EVALUATION AND AWARD

1. Contribute to all necessary actions relating to the procurement and tender process leading to award of contracts.

2. Prepare all necessary copies of drawings, specifications, bills of quantities and other tender documentation to be provided by the design team.

3. Obtain approval from client for proposed contract award procedure, terms and conditions and insurance arrangements in accordance with the CWMF.

4. Advise on and assist with the public procurement process for the works as required. This includes advice on the relevant procurement legislation and best practice, including the provisions of the CWMF.

5. In conjunction with the team lead, coordinate the assembly and compilation of tender documentation packages for issue to contractors & specialists.

6. Contribute to tender directions, requirements and instructions to tenderers for incorporation in the tender documents.

7. Contribute to the works tender process, including invitation to tender, tender queries, receipt and evaluation of tenders, report and recommendation through to compilation of contract documents for signature with the contractor.

8. In conjunction with the quantity surveyor and the other design team members, report on tenders to the client and recommend chosen contractor.

9. Advise in relation to requirement for advance purchase of any long delivery items which may affect programme.

10. Contribute to the preparation of tender analysis, updated post-tender developed cost plan review, and expenditure cash flow for the project.

11. Assist in and carry out as required all necessary actions relating to the procurement and tender process leading to award of contracts.

12. Contribute to an evaluation report relating to the technical and financial merits of contractor's/ specialist's submissions. Identify any conditional issues that require resolution prior to accepting the tender. Provide recommendations to the client dealing with tender adjustments, revisions or amendments that may be required in order to meet the approved budget. In consultation with the design team, report on tenders to the client and recommend chosen contractor.

13. Advise in relation to requirement for advance purchase of any long delivery items which may affect the programme.

14. Contribute to tender analysis, updated post-tender developed cost plan review, and expenditure cash flow for the project.

15. Assist as required in the preparation of the contract for building works and signing.

16. Assist the design team leader in organising and co-ordinating collateral warranties required from the building contractor and specialists.

STAGE 4: CONSTRUCTION

1. Ensure sufficient resources are available at all times during the construction to meet information delivery and contract response time limitations as they arise.

2. Ensure that all necessary notices, certificates and other obligations related to the design elements required under the contract are discharged in accordance with the contract and that the client's rights under the contract are protected.

3. Advise the client generally regarding statutory duties, particularly with regard to health, safety, sustainability and the environment.

4. Assist in examination of contractor's site set-up and proposals for constructing the works safely and in accordance with the contract. Liaise with contractor's temporary works designer. Keep the client and design team informed of potential risks or changes to the design elements which may affect the brief, cost, quality or programme.

5. Assist in evaluation and approval or otherwise of contractor's/ specialists value engineering proposals, their incorporation in the contract, and associated cost adjustment as required.

6. Assist in the preparation of information delivery schedules by the contractor in consultation with the client, identifying when design information is required by the contractor for ordering, construction or other purposes. Check and confirm that this is co-ordinated with the design information delivery programmes.

7. Prepare a detailed coordinated information release programme to meet the contractor's information schedule and programme, fully addressing all necessary resource inputs, deliverables and approvals, with input as required from the other consultants. Provide sufficient copies of each of the final drawings supplied to the contractor for the purpose of constructing the works.

8. Receive and respond to contractors and/or specialist's requests for information (RFI) providing additional design input and/or clarification where required. Provide necessary documentation to confirm status of RFI closure.

9. Receive, review, and evaluate contractor, subcontractor or specialist production drawings, shop drawings, method statements or other relevant submissions and respond, amend, approve or as otherwise appropriate to ensure compliance with the contract. Provide input into the technical evaluation of method statements and risk assessments issued to comply with the building design and health and safety regulations. Respond promptly to all such submissions in accordance with the agreed procedures for approval.

10. Assist in the preparation and maintenance of a fully documented record of all submissions made by the contractor or specialists and responses to same.

11. Advise the client on proposed variations or changes to the works as they arise. Participate in timely assessment of the impact of the proposed variation on cost, quality and programme and advise the client prior to any work being instructed or carried out. Participate in cost monitoring, cost control and design change control procedures for the project and implement these as required throughout this stage.

12. Assist in providing a response from the design team, and advise on the effects of a proposed change to the design of the project, in accordance with the change control procedures.

13. Assist in examination and report on any variations and claims, including those resulting from delay/disruption, pertaining to the works.

14. Assist in the process of anticipation and identification of any project risks, delays or compensation events, and implementation of appropriate action to address any issues or other events which may threaten the project objectives.

15. Assist in examination and report on contractor claims for delay, disruption or the like.

16. Participate in procedures to monitor and record progress, quality and cost, and to deal with any issues or problems that may arise.

17. Oversee, inspect and approve all tests, prototypes, samples, mock-ups or the like related to the design to be provided by the contractor/ specialists under the contract and advise the employer's representative in relation to any necessary instructions.

18. Where necessary advice on the need for any additional inspections and/or tests required. Where appropriate propose recommended suppliers, provide brief and obtain costs for the provision of such additional tests.

19. Carry out regular visits to the works for the purpose of monitoring and inspect and record, to confirm that the works are being carried out in accordance with the contract. Identify and advise the employer's representative in relation to specific work elements which require inspection or testing prior to the work being covered up. Site inspection observations regarding quality and conform to design and specification should be raised and minute at the formal site meetings.

20. Liaise with the other consultants, client and key stakeholders in relation to building fittings and fixtures and installation of specialist equipment.

21. Coordinate with the other consultants as required in relation to the issue by the employer's representative of all relevant instructions, objections or other communications to the contractor in accordance with the terms of the contract.

22. At the periods for interim payment, provide advice or approval as required in relation to certification of payments to the contractor in respect of the design installations in accordance with the terms of the contract. Carry out inspection and approval as required of materials, components, or other elements of the works manufactured, fabricated or assembled off site as required in advance of delivery or payment.

23. Participate as required in dispute resolution procedures in relation to day-to-day disputes which may arise during the contract and actively assist in the resolution of these as they occur. Assist as required in relation to formal dispute resolution procedures where necessary in accordance with the terms of the contract.

24. In conjunction with the other consultants, review and comment on Contractors, sub-contractors or specialists' proposals and programmes for commissioning and performance testing of the works. Where required, witness commissioning and testing. Examine test results submitted by the contractor and advise on areas which require further testing prior to completion. Agree, coordinate and comply with procedures to verify and confirm acceptance of systems or elements of the works.

25. Carry out inspection of the works on completion of the works, or part of the works where applicable, and prepare a list of defects. Notify the employer's representative of all snags and defects identified for issue to the contractor. Carry out inspection of the defects remedial works upon notification of their completion by the contractor.

26. On request from the employer's representative, provide certification that the works have reached substantial completion.

27. Assist in evaluation of any outstanding works still to be completed prior to confirmation of substantial completion.

28. Assist in evaluation in relation to partial / sectional completion of the works if required in accordance with the terms of the contract.

29. Provide all necessary advice in relation to taking over of part or a section of the works in advance of substantial completion, if required, in accordance with the terms of the contract.

30. Provide opinions on compliance with planning and building regulations at building handover to the client and employer's representative.

31. Prepare as-built drawings. Prepare, assist in and coordinate as required the compilation of as-built drawings, operation and maintenance manuals, the health and safety file, testing and commissioning certificates, maintenance specifications and proposals for maintenance contracts.

32. Review and comment on the contractor's draft operating and maintenance manuals, health and safety file, record drawings and any other related documents to verify compliance with the contract documentation. On issue of the final set of the documentation check that any comments made have been addressed.

33. If required, arrange for provision of information to independent auditors, quantity surveyors, tax advisors, insurance surveyors, purchasers, tenants and the like.

STAGE 5: HANDOVER OF WORKS

1. Assist in and provide necessary documentation in relation to the preparation and assembly of and delivery, within 4 weeks of substantial completion, to the client of two complete bound sets of completion documents in hard copy together with one set in CD or other digital format, including as-built drawings, detailed technical specification, Specialist works as-built drawings and specifications, all results of specialist's test or any other tests carried out during the currency of the project health & safety file, operating & maintenance manuals, maintenance specifications or other relevant documentation.

2. Provide advice and recommendations to the client in relation to building maintenance, and the training of the managers and maintenance staff who will be responsible for the operation, safety and maintenance of the new facility. Participate in training and maintenance seminar.

3. Provide input and assistance as required to the quantity surveyor in settlement and finalisation of contractor's accounts and the project final account. Provide technical evaluation, assessment and adjudication in relation to contractor's claims where applicable.

4. In conjunction with other consultants, monitor the contract defects period. Compile a list of defects in the works, one month before the end of the defects period and issue a schedule of defects/snags to the employer's representative and client, for issue to the contractor. During defects period advise the employer's representative on any defects which require urgent/ immediate attention.

5. At the end of the defects period, carry out a final defects inspection, and on satisfactory completion of all defects, notify the employer's representative accordingly.

6. Review risk register and transfer the information to the PSDP for inclusion in the safety file.

7. Participate in and provide technical input to the client's post completion review. Assist in design team project review to explore experience gained and lessons learned for future projects.

Appendix 11 *Interview participants (Case study and validation)*

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT ENGINEERING PRACTICE
INTERNAL - Building Services Engineering - Technical Practitioners				
1	MEP Engineering Director	*Master in Engineering*	28	4
2	Mechanical Engineering Lead	*Bachelor of Science*	12	4
3	Senior Mechanical Engineer	*Master in Engineering*	8	3
4	Project Mechanical Engineer	*Bachelor of Science*	5	4
5	Electrical Engineering Lead	*Bachelor of Science*	16	6
6	Senior Electrical Engineer	*Bachelor of Science*	12	2
7	Project Electrical Engineer	*Bachelor of Science*	5	5
INTERNAL - Programme and Cost Control Personnel				
8	PCC Practice Lead	*Bachelor of Science*	28	28
9	Lead Programme & Cost Consultant	*Bachelor of Science*	25	25
10	Project Programme & Cost Consultant	*Master of Science*	9	9
EXTERNAL - Mechanical & Electrical Engineering Contractor Personnel				
11	MEP Coordinator	Bachelor of Science	25	10
12	Electrical Engineering Contractor Lead	*Bachelor of Science*	32	20
13	Mechanical Engineering Contractor Lead	*Bachelor of Science*	15	10
14	Cost Control Manager (Electrical)	*Bachelor of Science*	9	5
15	Cost Control Manager (Mechanical)	*Bachelor of Science*	11	7

PARTICIPANT NR	DISCIPLINE	QUALIFICATION	POSTGRADUATE EXPERIENCE	TIME IN CURRENT ENGINEERING PRACTICE
EXTERNAL - Building Services Engineering Consultants				
1	Managing Director (MEP)	*Master of Science*	28	28
2	Managing Director (MEP)	*Bachelor of Science*	25	15
3	Technical Director (MEP)	*Master of Science*	17	5
4	Technical Director (MEP)	*Bachelor of Science*	19	5
5	Technical Director (MEP)	*Master of Science*	14	2

Appendix 12 *Case study interview framework*

NR	INTERVIEW QUESTION	GENERAL	PROCESSES	PEOPLE	TECHNOLOGY
1	How would you best describe the building service engineering design process?	×			
2	Ineffective design management results in extended design timescales and the production of poor-quality tender documentation. Any unresolved design issues must be resolved at some point for the building services installation to be successful. Explain how your professional experience relates to this trend?	×			
3	What was once deemed the province of a craftsman now demands the services of a body of highly educated and specialist trained professional engineers. However, it is inferred that academia alone does not form a solid foundation for engineering graduates in the building services engineering. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?	×			
4	Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?	×			
5	As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?	×			
6	Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between design and construction professionals, hence the need to improve the technical/social dualism. What are your thoughts on this statement?			×	
7	Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy, but from the managerial complexity. What is your experience?			×	

NR	INTERVIEW QUESTION	GENERAL	PROCESSES	PEOPLE	TECHNOLOGY
8.	It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement? How do you envisage such communication problems may be improved?			×	
9	The building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management during construction. What is your experience?			×	
10	Dissonance between designs in an multodisciplinary practice is often brushed-under-the-carpet at design stage. How do you relate to this phenomenon?			×	
11	Successful building services engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?			×	
12	Due to commercial and time constraints, practices are often unable to meet learning targets with formal training programs, and as such resort to informal training programs. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is an organisation skilled at creating, acquiring, and interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?			×	
13	The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage, and consequently, dysfunction in practice. What is your experience during the project life-cycle?		×	×	×
14	The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos which provides further challenges. Has your team experienced this phenomenon, and what are your concerns for future-multidisciplinary design?		×		

NR	INTERVIEW QUESTION	GENERAL	PROCESSES	PEOPLE	TECHNOLOGY
15	Technical coordination in the context of building services engineering means working with and influencing other members of the design team so they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people by gaining their willing cooperation is a major aspect of engineering practice.		×		
16	Design coordination is a purposeful and goal-oriented activity which aims to coordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design coordination?		×		
17	It is recognised that 75% of the problems encountered at construction stage are generated at the design stage but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40-50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?		×		
18	Design issues cannot be resolved by squeezing the design process, achieving milestones with less information or making explicit decisions to change the design process. Describe your experienced of this phenomenon?		×		
19	Information management is concerned with ensuring that the right information is available when required in the right format. Have you adapted a 'not reinventing the wheel' approach to your design?		×		×
20	Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?		×		
21	Performance measurement provides a means of distinguishing between perception and fact at three levels; individual, project and organisational. A significant question for design performance measurement is whether improvements in design alone can lead to step changes in performance. How is performance measured in your practice?		×		

NR	INTERVIEW QUESTION	GENERAL	PROCESSES	PEOPLE	TECHNOLOGY
22	Early engagement between the client and the technical design staff during the design process; In your professional experience, do you believe this communication correlates to the quality of design deliverable output.			×	
23	The process of reflection in engineering design engineering is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design so as to engage in a process of continuous learning?			×	
24	A successful building services engineering entity achieves client satisfaction, provides technically sound professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.			×	
25	The use of design decision-making tools in the propensity of power distribution, general and emergency lighting, lifts, lightning protection, heating, ventilation and daylight simulations, wind and solar energy, etc. may be useful for guidance. In your professional experience, how accurate are decision-making tools in your specialism?				×
26	Building Information Modelling (BIM) is not just a fancy 3-d model. It is about moving away from traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2-d to 3-d modelling during the design process.				×
27	MagiCAD offers integral BIM 3-d software for building services engineering design. It is a powerful enhancement tool developed to save time with more user-friendly, flexible, intelligent, and parametrical user environment. How has your experience been thus far?				×
28	Inefficiencies in engineering practice at design stage are noted as follows; - Lack of design coordination between disciplines leading to installability issues, - Poor communication, - Deficient or missing input information, - Duplication of effort, - Unbalanced resource allocation, - Erratic decision-making, and - Poor design quality	×	×	×	×

	As the design process is found to be a major source of problems at construction stage, even to the extent of undermining systematic management, the following deficiencies were identified: - Inferior quality of installation, - Time delay of installation, - Increased cost of installation, and - Redesign. As a direct consequence of these deficiencies, the impact in design consultancy practices is significant. The primary dysfunctions relate to: - Professional dissonance, - Poor design quality, - Redesign programme, and - Redesign cost. How has your organisation dealt with practice dysfunction?				

Appendix 13 Case study *interview participant transcripts (Internal – BSE practitioners)*

Reference	*Engineering Management*
Attendees	*Engineering Director, Raymond Reilly (Researcher)*
Date/Time	*20th December 2018, 1.00pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*1 (BSE Practice Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.

The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

- ***i)*** ***the design and construction stage in the context of people, processes and technology, and***
- ***ii)*** ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Well, I consider myself to be a logical thinker and the mechanical electrical design process fits into the way I think. I try to solve problems and I like to find solutions, I like to find problems so I like to be presented with those sorts of things that I can work my way through, I like providing something that leads to something. So, you're creating a scheme or you're creating a solution to a problem; you're talking to clients to find out what their needs are, what their requirements are, what their preferences are while at the same time complying with all the relevant standards so I do find it interesting and fulfilling and the more complicated and confusing the project is, the better. I don't like repeating design strategies, if you know what I mean, there needs to be a bit of variability I think in design to keep you interested, but I personally enjoy the design process more than anything. I'd be quite happy sitting designing all day.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response On that, I have an ongoing serious problem and it usually, in my experience, is largely driven by let's say design engineers' lack of training or lack of mentoring or full appreciation of how things are installed on site. Therefore they think very much, can be accused of thinking very much of oh it's just a line on the drawing and they leave it to the contractor to sort out the problem which leads to unnecessary expenditure fee and additional queries, additional answers required, additional clarification, meetings, workshops, to me they're largely unnecessary, that the engineers who were designing knew, from basically an information point of view, that an individual on site needs to pick up a drawing and have the relevant information to enable them to progress. Not having a mentality where I don't need to go into that detail because the contractor will fill the gaps. That's pure design, it's pure thinking, it would be difficult for the contractor and that's why we get unnecessarily fees. I think it's more prudent to spend more time on design and reduce your time on site and reduce the emails for answers and explanations you have to give to support your design and I, I criticise and have criticised engineers for I look at their drawing and I go that's all just lines and symbols, where's the notes, where the explanation, where's the sections, where's the detail. How does a guy know what height that's measured at, how do they know they're offsetting around that, how do they know which structure, or are they just keeping the same line. If you don't tell them, they're going to take a standard line and the ceiling should be three feet higher than it's going to be.

These sorts of things and it largely comes down to, I think, a lack of understanding of site and how to install. But I would say that because I served my time and studied part-time, so I am biased that way. And I do get less questions than others.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response That is sort of following on from my previous answer. Having served an apprenticeship and then having studied part-time et cetera, I realised that – and indeed I am chair on the Industrial Liaison Committee at the Ulster University, BSc, BEng, MSc in engineering and architectural engineering courses and I have frequently raised the issues that there is a lack of substance and depth with regards to high designs are implemented and thought through to which the academics have repeatedly said 'Well, we're teaching them how to think, we're teaching them the processes, and again that experience when they leave, which I think is very narrow-minded. I have said to them and I will say to anybody, when you get a graduate out of university, you then need to basically teach them everything from scratch. They may know how to size a pipe, but they won't know how to design a system. They may know how to size a pipe, but they won't know how to design a system. And all the issues associated with it, so I do believe, particularly in our marketplace and I think in general engineering, there's a gap and it doesn't all come from academia and I have said degrees now that are modularised, you only ever have to be 12 weeks' smart to get through a module. And I think degrees can be overrated with regard to these things. You do not need a degree in all its many forms to carry out the vast majority of the work that we do on a day to day basis. You do need to have a practical understanding and appreciation of what you're designing. And that is sorely missing.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response I would agree with that totally. It's no good being the best engineer on the planet if you can't communicate with people and the client has no time for you. It's no good always being right if the client can't connect with you and you come across in a very undiplomatic way. When I recruit I don't recruit for the role, I recruit for the organisation, so I won't necessarily. I basically don't go necessarily for the highest qualified because that doesn't really matter to me. It's how they will fit within the team, how they will communicate with the clients and communicate with others and sell the business. And are they good enough to carry out the activities, that's good enough. It's no good having someone that thinks they're a gift to humanity in engineering if they fragment the team, create friction and can't communicate with clients.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response That can be a difficult one. I have seen design managers of what I would consider to be different levels of experience in the design field. Some having none. And some having quite a lot. Particularly in the contract, you know, where the contractor may appoint a design manager to oversee their sub-consultants, it could be Acomb or anyone else, to manage a design process, it can be problematic and has been where the design manager doesn't understand the design process and has actually never designed. It's not their fault, it's not the contractor's fault. The other side of that is you can have design consultants who are so focused in their role that they don't have an appreciation of the other disciplines and the other design issues that affect other parties. So, there does need to be some kind of translation is carried out. That can come with experience but not necessary just experience. It can, like anything, be taught, and I have worked with plenty of very experienced engineers who are not in the slightest bit interested in other disciplines and how things interface. All they're concerned about is their little design. So, there does need to be I think a widening of through experience, through mentoring or through academia, where people are taught how different, different disparate design interface with each other and can oversee that. You will sometimes get PMs who are previously QSs implementing design manager role. And it never ends up as successful as it could otherwise be. The best way is to have someone who has designed, who's designed with multidisciplinary teams, understands how the teams are required to source information and interface with each other and are best placed to do that but a lot of the time, people have not designed and led multidisciplinary teams. I don't know if that's answering your question but that's my thoughts on it.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I would more or less agree with that statement. Contractors can have an overly simplistic view to a solution at times. And designers can have an overly simplistic view to a solution.

Also, designers can sometimes unnecessarily overcomplicate the issue and do need almost sometimes a steer from a more practical stream, like a contractor, to pull them back into line. Designers can over-design or over-engineer because they know more than they actually need to know to solve that solution. And the contractor just wants the problem solved. So, again, similar to better designers, people can be better designers by better understanding how things are installed on site and getting some practical experience. Same can be applied with regard to getting better experience of how contractors operate and what their issues are. And indeed having design managers who work for contractors working in a design office and better understanding how they work. To me there has to be a bridging and that can only come from working in collaboration or having some sort of relationships with different partners, because no one entity in its current structure, design consultant or contractor can necessarily do that on their own.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response The vast majority of day to day issues, design issues, when I come across have been solved and are implementing design traditions from things that you've done before. There's very few times you have to come up with an innovative bespoke solution. Although that does happen. Therefore the better the process, the resourcing of the process, the design process is planned out and you've got as I said design manager or a multidisciplinary design partner who can understand the intricacies between the different disparate teams, if we can call it that, the different disciplines, the better those things can flow together. But the vast majority of times, and I'm guilty of it, but the more jobs you do, actually the more bold you can become with it because you've seen the problems before, time and time again. You see them coming, you know it's going to happen and there's very few things that are new anymore and that's why you're right to do more complicated projects because then you have to think and come up with innovative solutions that are not the run of the mill. The vast majority of jobs, the solutions were very, very similar from what's happened before so what may seem innovative to you or a less experienced member of the team is run of the mill and ordinary to someone who's got a bit more experience.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I do agree that that is an issue. I agree that there's a lot of people in management positions who really shouldn't be in management positions or they're there because of their experience and they couldn't go any higher within the design discipline and they end up managing activity. That doesn't mean to say the best place for doing that, particularly when you have projects where design engineers will sit down and commit to the design projects and will not even have read the scope, the design, the partner management might not have even read the scope and you end up with engineers potentially over-designing and wasting unnecessary time doing unnecessary deliverables because this is the way they always do it. Simple things like on-tack designs or on-tack calculation strategies and building all these things up and they may not actually need to do it. But they're spending time, effort and it's not being managed out. Managers need to better understand what the client requires, steer everything that the design partners do, that the design team do to give what they client requires within the confines of the scope. And not an awful lot of time do managers actually read the scope. They get a project, it's about X, they've done and X project before, they know how to do it, they give it to team members, team members get on with it, they may have not done an X project before, maybe they have become very repetitive but the first time they've done it or the previous times they've done it, they may have over-engineered it, they may have done it wrong, and it's not properly looked at. It is simply thought - you've done that before, okay, you can do this now. But was it good enough before? Did they lose money before?

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response There is a statement that is often made to me by architects and I do agree that it's hard to get a good building services engineer. I do hear that time and time again and I regurgitate it. I am a building services design engineer so that's what I know most about.

I can't comment on the structural or the civil or architectural aspects on it but purely from a building services point of view, there is not enough, I believe, understanding or appreciation of the issues that we've come across on site. Are the activities carried out on site and at work on site. Transition arrangements, sequencing of work, never mind the programming, the testing, the commissioning, the recommissioning as other phases come online and the end-users, what their requirements are, how are they going to live with this for the next 20, 30, 40 years. There are gaps. I can only comment on the building services field and that to me is clear and only by I think having more experienced people getting involved in that can you improve that situation that they can factor that in. But unfortunately if it's an individual thing, I have worked with plenty of experienced people who will pump out work, which to me is dubious in the detail that it has and the problems that it's going to create onsite and I would have felt should have known better. So, it is an individual thing.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response It can be the case, it does happen, and I have actually surprisingly seen that there's more - there can sometimes be more collaboration between non-multidisciplinary practices. Where, if our company was carrying out building services. And we were dealing with architects or engineers, structural et cetera, in another practice. But it actually may be more communication taking place that wouldn't necessarily happen within the multidisciplinary practice. Because there can be a certain assumption that we're all working together and if they want to know anything, they can come and ask me. And it's not really closed out. I have noticed a couple of times that there's more flow of information that's external partners than internal partners which can be surprising. You know, you'd think it would be more joined up. That may be not necessarily the case.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Management to me is about setting parameters by way of performance of the team but ensuring the team have necessary resources, drive, commitment, understanding, ethos. And skills and support to ensure that they understand their role. It has everything they need to fulfil their role. They are connected with the project. It's not just a task. They are the right people connected with the project and the client's needs that the project is important to them. And their reputation and that of their organisation is important to them. And they want to be the best they can on behalf of the client. Because that's what will lead to a happy client and repeat work. And no single job is about that job in itself. It's about all the future work you may under perform in this project. Therefore to me management is about making sure the job is right, delivered on time, obviously, meets the client's requirements but also in a manner that the clients are happy and felt that they gained by working with us, and they would look forward to doing it again. Because we were easy to work with, we were collaborative, we were supportive, we were comprehensive, and they felt we were a safe pair of hands and that's far more than just getting your cables or your pipe sizes right.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response There's two sides to this. The learning organisation, it has to learn. And constantly appraise, and there is the learning delivery back to the staff members. The organisation has to provide the necessary training, mentoring to the staff members to make their feel and valued. Any of us can deliver more on behalf of your organisation. That requires people connecting with less experienced members of the team and making sure they understand reasons for different actions, how to carry out different tasks. Only recently I've had issues where I set down with certain more junior members of staff and gone through different things. And I have been surprised, having been for so many years that they didn't know certain things. But yeah, they would have been mentored. I have therefore questioned the mentoring level and I had discussions with certain parties about, along the lines that members of staff should know that by now and why did they not know that. Because you're meant to be mentoring them. And I would expect them then to understand that. And are you making enough time for them. So, the manager has to ensure that those who are coaching, and mentoring are actually coaching and mentoring to a qualitative level. It's not a mechanical task. It's a case of at the end of the day what I know, the person that I'm mentoring needs to ultimately know what I know. As much as I can in the timescale that I have to get them to engage what comes along in the future. They're the ones going to be doing more complicated jobs than I'm doing, so they need to be better equipped and if I'm not getting adequate information, I'm not satisfied, they're certainly not. So, the same happens for those who are mentoring.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response There can be problems where people are designing in packets, as I call it. It's someone doing a design or someone doing containment design, or someone doing a ventilation design, someone's doing the plumbing design, or someone's doing the plumbing design, then they'll do the ventilation design. So, you run into a realm that designed and is largely progressed and they go onto their next system.
And it's not a truly iterative process where the previous design has been revisited so you end up with the second system or element to be designed because they're working around what was previously designed. Or they end up with gaps or problems being left, because you have run out of time and if I can use the ventilation or the pipework type arrangement, duct work is altered to accommodate pipe work routes and maybe it was better to route the pipe work somewhere else in the first place. Keep the duct work where it is. But it's easier to just rejig the duct work than it is to revisit the other designs. So, that's pure … but it can a danger where designs have progressed too far before you go onto the next stage or the next system. So, it's trying to contain yourself, but you're not making undue commitments to a building for example, and to change one knocks the whole thing out. Maybe you shouldn't progress it to the whole building. Maybe you should do it area by area.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Well, the haved worked in smaller practices and larger multidisciplinary international practices, more a problem for the larger practices where it's easier to have specialist team specialisms. In the smaller practices you wouldn't have a separate ICT , you wouldn't have a separate security group, you wouldn't have separate fire group. You wouldn't have a separate, you know, modelling group for example, sustainability team. You might not have the expertise that those specialist groups have in a larger organisation. But do you need it? Or do you just need enough so it's trying to get that understanding. If you have a team, we have a team and there are teams all over … any team is the same. If you rely on specialists outside your team, they're allocated a certain amount of time to brief them on the project, specialists would go away, do their bit and then give you their solutions back. There may be a little bit of to and fro if the solutions aren't much alike, that it doesn't work, but that's not really, I think, an efficient way to design totally. It may be that you've got the experts in-house and they can provide their expertise to and the specialists can provide their expertise to different disparate groups and teams around the country. But at the same time, would it not benefit the design if those carrying out the vast majority of the activity on the ground, so to speak, have a better appreciation of what some of the special activities are. So, they can work through and better implement their design on the back of what the specialists are going to come back with.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response I'll just say different disciplines like building services, and structures. You know? The best way I believe to implement part of the design and is to constantly be interfacing back and forward and not 'Here is my design' or here's this part done. It needs to be an ongoing live connection between the two different or the three different or the four different or the five different disciplines on an ongoing basis. It's no good designing something and then going right, I've done this now, can you look at design from a structures point of view. Can you check your structure with regards to this. Or structures doing their part in going right there's my bit. You engineer what you've got to do around my structure. That's pretty poor, pretty simple. How difficult would it be for the two to collaborate and do what do you need to do? How can you accommodate each other so you're not reworking later on. So, it's an ongoing thing that people should be collaborating all the time and it is extremely frustrating and poor that people sit in their silo and design their solution, issue it to someone else and then expect someone else to modify their design to accommodate your design. That's not the way to do it. Maybe that costs the client more in doing that and maybe that's less productive from a manager's point of view.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response Well, my understanding of design co-ordination is ensuring that the different design parties are aware of each other, are aware of their presence, are aware of their system requirements, and can factor that into their design. I accept there's too much emphasis today on the idea of BIM or [00:30:26.9] being the all-encompassing design co-ordination tradition for projects. And I think it's a cop-out and it's really just a glorified space planning exercise. And before we had those technological advancements so to speak, people gave more time in designing in 2D and factored in more of the issues then, now they design quite simplistically and try to replicate it. Its designed directly in 3D and then try to replicate it on 2D and 3D and then co-ordinated. It's not good. The different parties need to be collaboration, communication between the teams and not relying on software to pick up shortcomings in your design philosophy.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response First of all, I think if I can be critical of clients, but I understand why, not enough money is set aside for design. It becomes a race to the bottom, the cheapest fee and therefore you get compromise in design. So, previously where there would have been scaled fees and there is more or less standardisation across the marketplace, if there was adequate time, I consider the implications and the issues of the design. And factor problems and solve problems before they occur on site. But if you have the lowest fee level, then you have to produce complex designs with half or quarter wanted or needed to do proper comprehensive job, there are compromises will continue to impact on what happens onsite. And on the fact that high construction costs. As I'll say to clients, the more design fee you pay, the better and more comprehensive design you will get. If you think paying someone next to nothing is going to get you the same quality of design which you would get if you paid them three times more, and all, it doesn't work like that, because engineers will have approaches that they will end up, they have issues et cetera that will increase installation or construction costs. That's one side of it. The other side of it is that design engineers back to that appreciation of what happens onsite, a lot of design engineers and architects do not understand the cost of things. Therefore they do not understand or fully appreciate if I do this am I saving money, how much am I saving, is it worth doing that? Is it worth spending this money now than on something else or is this going to cost a lot of money. Does that make a change to me? Is that going to cost, is that going to save £500 or cost £5,000. A lot of the times they don't really know. And a shrewd contractor can steer a ship quite clearly through the gaps in a lot of designs and pick up additional funds and improve the contract value because the design parties don't totally understand how they can basically get extra money on the back of shortcomings in the design. Maybe gaps and the contractor's fills it with money.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Well you can't squeeze the design process, it has been squeezed and to me designs are not as good as they were. Designs typically going out the door are of a poorer, lower standard than they would have been 20, 30 years ago. I'm working 38 years, I can see what I was doing as a young guy at 20 compared to what is going out the door for me as a man of 54, there is a total change from what … and we're technologically far more advanced, but because of that, that also creates an issue which the designers don't totally understand what they're designing. The software is helping them. Rubbish in, rubbish out can be an issue and you have less thought out designs. And I think the design process has suffered by a combination of programme and things being rushed out the door and always effects will happen onsite. Co-ordination, contractor, gaps, insulation costs, works. More time you can give over to design, thought out considered design, the better it will be for the client and the contractor and the programme but unfortunately you don't get that time, you don't get that fee and a lot of time now you don't get the team members who can do that.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response What I try to communicate with the team that they should be putting together information they require from other, from the client, from other design parties, so not necessarily making assumptions. If they don't get responses in a timely manner, then they have to progress assumptions. So, everybody knows what they're designing to. That there's actually been a more recent thing that I had to implement because parties had been designing based on their assumptions and they never did discuss them with anybody. So, it's important information we require, and all designers require different information from different parties at different times. If it's documented, the responses or lack of responses are documented and the assumptions are communicated, therefore they cannot be held unnecessarily to account if there's any issues later on. So, the design information flow process is vital to putting together a co-ordinated, fully appreciated and delivered solution that meets the end needs at the right budget.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Not that that happens an awful lot, but sometimes it does. The vast majority of building service engineers are squeezed into the end and site preparation, site clearance, steelwork, all of that, the architectural construction type issues get a lot more time in the building services comes along quite late in the day. And then has to undo a lot of activities that have been carried out by the other parties prior to them even arriving onsite. There may be design benefits by absolving the building services design more fully into it. In as detailed a manner as possible, particularly aligned for commissioning. So, where that's not allowed, design is always, it's always a weaker, poorer programme and you end up with quality issues because you're squeezed on time, cutting corners, testing, commissioning, things not signed off. At the same time that the building services are designing the programme, they won't fully understand the other issues themselves. So, any one programme will be weaker, if a single party carries it out. And largely it's the builders programme and they'll just piece it together. But even that is not the proper way to put together a programme.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response Performance in my practice is measured not just about getting things done on time, it's about the quality of the design, it's about how the team member communicates and interfaces with other parties, commits to providing the best solution in the best manner possible for all concerned. So, it's not a single you've got that done for that date, you're a great person. If you got that done for that date and fragmented the team, offended and upset other team members and what they had done may not be as good as it could otherwise have been. So, I use this bit of a corny mantra, everything we do and everything we are could be better. Can always be better. And if we think we can't, then we're selling ourselves and everything else short, so always think you can do it better, be more open.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response I believe it does definitely, depending on the nature of the client that is. You can have ill-informed clients and you can have well-informed clients. Where there are well-informed clients it can definitely enhance the nature of the information to client and benefit the scheme in the long-term. If you're working for example with different operational groups within hotels. Or within healthcare, that sort of side. Their experience in dealing with certain issues can be very beneficial to a design culture. However, if you've got an uninformed client, so to speak, where it's a project and it's a standalone entity and it's not their area as such, they just build it and sell it or build it and rent it, whatever it is, their views might actually slightly get in the way of design, therefore they end up with a compromised solution of watered-down design that they're criticised for. So, you've got to steer the course somewhere between the two so you're not selling yourself short with regard to an ill-informed client and you're not over-designing and then wasting time for a very informed client and steering a better course in the middle. It makes the two end goals at the right level of design.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Definitely. And I would expect everybody else who works with me or within my team to do the same. It's a smack of arrogance, I think, for someone to say I have done a design and it couldn't be any better. That's a nonsense. Everything could be better. Maybe they got more information that it could have been better or maybe we could have asked more questions and it could have been better, had more time, had more fee, had different input from different parties at the right time and it could have been better. If they're not thinking on that level, I would worry that we're not progressing, they're not progressing and doing as good a job as we could. So, every job I do, I've looked back on every job I've ever done and always will and hopefully I always will and think I could have done that better or even if there weren't problems, just say I could have saved time and done that far more efficiently or could have done that more comprehensively and that would have benefited the project. Without any criticism from anybody else, criticising myself.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response I think the major contributor to a harmonious and productive working environment is people respecting and ideally supporting each other. Because I've often used the example we don't have to like each other but we have to get on and we have to support each other. And that's the key thing. So, we support each other in everything we do. We keep an eye out for each other and people realise they're not on their own and they're not going to be thrown under a bus. It makes your designs better, it makes the environment a more harmonious environment, people more content and hopefully the client gets a better scheme at the end of the day. And my battery's about to go.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response I can get a lot of decision making design tools to give me the answer I want. So, I'm very mindful of those sorts of things. As I say to the team members, if you can't work it out with a piece of paper and a pencil, you're not an engineer, so think about it first and then check it and verify it or get support or an added view from design software. But if you're designing straight into software and you expect it to be right, with truly understanding what you're doing on the intricacies of the software, then you're partially designing blind. And there's going to be issues. So, you should always have your knowledge from first principles and then substantiate your design through software.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response The main issues are two-fold really. Not every partner that we would work with either internally or externally is adequately scaled up to do that. And also the knowledge base which requires these packages internally. I believe if everybody else we would interface with had the same sort of – not the same but adequate levels or equivalent levels of software and understanding as we would have and our knowledge was better, then it would all come together far more efficiently and provide a better scheme. But we're in the infancies of this. We're only rolling out and a lot of smaller practices are not yet scaled up to the extent that we have had to build architectural models to enable us to design the services in an architectural building. Because the architect didn't have the capability.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response None.

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Are you sure you couldn't have got the question a bit longer? Well, again, this is coming back to a few points raised before. We need to have and I'm going to use a term even for myself, constantly learning, and we should always try and make it improve. Better people doing better things in a better way and at the end of the day a contractor will always find a problem onsite. And I feel it's our obligation to try and minimise that happening or prevent it happening altogether. So, the only way that can come about is if we are better at what we do, we manage it, knowledge, the experience, the exposure, the understanding, the co-ordination, the asking the right questions of the right people at the right time, implementing iterations forward through checking them, all of those things could be better, more thought out and integrated into our fee to enable us to make sure things go up right first time, cost-effectively meeting the programme. We just need to be better at everything we do.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Mechanical Engineering Lead, Raymond Reilly (Researcher)*
Date/Time	*6th February 2019, 2pm*
Venue	*Adelphi Plaza, Dun Loaighre*
Participant Nr	2 (*Mechanical Engineering Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) ***the design and construction stage in the context of people, processes and technology, and***

ii) ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services design process?

Response I suppose the building services design process, it's very much an iterative, collaborative process. You start from the very beginning with a blank sheet of paper with a number of multidiscipline engineers or architects around the table. You go through various different options which then slowly hones the solution down to you know, one or multiple solutions and then you won't move onto the next round of iteration and collaboration, onto the next level of detail and I think that process really continues right through to the design is finished and nearly almost right through construction to the project completion in various different sizes and various different stages.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation. Any unresolved design issues have to be restored at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response I think the ineffective design management really at the outset of the project has an impact on that. A lot of the work we would do would be at applying stage and then in through the various different RIBA stages or government forms of contract stages. So for example you've at planning stage, stage 1 or stage 2A, you're making decisions really that are going to, you've only one chance to make those decisions and they're going to affect the whole course of the project and if you don't make the correct decision correctly at that point then it becomes too late at later stages. So it's very important that the design is managed correctly from the outset, to make sure that everybody knows what decisions need to be made and to make sure that they're made correctly and effectively.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response I would say that it has in - with the benefit of hindsight it has. I mean when I look back at some of the things that I'd encounter now on a daily basis. I'm still referring back to things that I would have learned in college in terms of the way it has taught me to think about things and approach different solutions. I think all of that, taking all of that into account, yes it has prepared me.

But I'd say if you asked me that after one or two years in the industry, would say that it hasn't, because I think generally starting out I would have felt, and a lot of my peers would have felt, was that we didn't have enough practical experience to enable us to be design consultants from the outset. I suppose that can probably be said on any education course and it's very, very difficult with something even as specific as building services engineering, to be able to prepare graduates for the wide variety of roles that you can get afterwards. But I think if it was to improve, I think maybe some more practical, hands-on projects, more collaboration with industry consultants or other companies along with those projects. So for example we did a lot of design projects in-house on speculative buildings with lecturers who probably didn't really have a lot of design experience. I think that would have been, there's an opportunity there to go to consultants and maybe collaborate with them and use life projects, where people were actually designing, I think that would have probably helped us in that respect.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead. Whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response I'm not sure I would necessarily would agree with the statistics but I can both agree with the general settlements that it really, you know, your technical knowledge can only get you so far and you know, personality and your ability to communicate and negotiate really as you move up through the ranks of an organisation, that becomes increasingly popular. In terms of our engineering team, I'd like to think that doesn't apply at the 85%-15% split doesn't really apply I think. I'd like to think that were able, very technical engineers who excel in a technical capacity but may not be so good at the rest of the bits and pieces. And I think there's a couple of initiatives in which are trying to address that people become technical directors which is basically still achieve the same level of seniority, through a technical role rather than through just management roles. Which, where you do need the personality ability to communicate, etcetera.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response I think it's a difficult gap to bridge, I think the best design managers are those who have the experience of being building services engineers. I think it's fair to say that - I wouldn't say fell into but more just ended up as design managers through career progression. So I think maybe in terms of that transition, it's trying to identify somebody from the very outset that 'Yay, I want to be a design manager but I'm going to spend my first 2-3 years as a design consultant. And after two or three years I'm going to gradually phase down, spend less of my time doing engineering, more doing design management'. And trying to broaden your experience that way, maybe make it as a more formalised process, as opposed to people just ending up as design managers over time.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response Yeah, I don't know if it's a direct dissonance between the thought process, as much as there is an element of that, I think there's also an element that you know designers have been working on a project maybe for three or four years. Dealing with a client on a day in day out basis, have a very clear understanding of what the brief is and a very clear understanding of what the end product should be or they want it to be. So, sometimes it's not just the dissonance that you mention there, it's actually that you know the designers have a better understanding of exactly what the project is all about. Whereas the contracting team just want to get it built and that's what their goal is. So I think people have different goals as well as that dissonance that's mentioned. So I think the way to bridge that is to just make sure that everybody understands what the project is about, understands what the scope is, what the brief of the project is. So everybody is singing off the same hymn sheet at the end.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response There's, I think, yeah, when I would have started in engineering, I would have said that. I worked in a previous consultancy which was very much, a very technical consultancy doing large pharmaceutical, data centres, manufacturing buildings, all very complex high end, technical projects. And I always perceived that that was where I would want to stay because that was the most challenging thing to do. And I think in my current role I probably work on projects which are far less technically challenging but probably my role is far more challenging than it ever was due to that complexity of, you know, having to deal with various different contractual issues, dealing with, you know, HR issues, managing teams, managing resources and it is true to say that the longer you spend, the more experienced you are really. The technical difficulties become much less of a challenge in your career than the other, as I said more managerial, high level issues.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I think it depends. I mean if managers ask engineers to carry out tasks, I think it really depends on the level of person you're directing. I think if you've got a less experienced engineer and you're giving them more, you've to give them a task without giving them a lot of clear direction, that does end up in waste, because that person because of the level of experience they have doesn't really know how to approach that task. So really there's time wasted learning how to do it, making mistakes doing it and then coming back and asking you. Perhaps for the less experienced people it would be more beneficial to give them more prescriptive ways of doing things until they learn how to do it. I think then on the opposite, on the other end of that scale, it's people who are more experienced and they're given a task by managers in a more prescriptive way, without being able to you know, use their own brain and use their own intuition to solve tasks, that can often waste time because they're missing obvious design solutions there in front of them.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management during construction. What is your experience?

Response If the engineering design process is not followed correctly and there's a lack of coordination and a lack of engineering design solutions, thought put into the solutions, that would ultimately be found out and I think everybody who has worked in the industry would say, they could have numerous examples of how poor engineering in the design phase causes massive delays and cost increase at construction stage. And really the difficulty with that is, that it's very, very difficult to know even on a high level, looking at drawings, even for experienced professionals looking at drawings that are going out to tender whether they're correct or not, they may look correct, they may look coordinated until you actually go and build them on site, operate and get into the nitty-gritty of the complexity of the engineering solutions, you won't know exactly what's wrong. So I think really the only way to resolve that is to ensure there's enough time and enough resources during the design process and enough reviews and enough checking by various different people, to ensure that or at least to guard against as much as possible as errors that are going to cause difficulties during other stages.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Yeah, I think with a lack of design co-ordination during design between the disciplines. I think there's a lot of 'suck it and see' approach. People will say that they'll know there's issues there, either one discipline will know there's a co-ordination issue with another discipline or visa versa and often that just gets brushed under the carpet and said 'Oh we'll resolve that at a later date'. And with the best will in the world people saying we'll resolve something at a later date, a later date is quickly forgotten and that issue will snowball and become bigger and become an even bigger issue during construction. So my experience is this there should be no brushing things under the carpet, if there's an issue it needs to be resolved straight away because if it doesn't get resolved straight away it invariably does not get resolved.

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in the building services engineering practice?

Response I think management in the building services engineering practise, I do believe the first and foremost has to be technical management, the leaders in a technical organisation need to be extremely technically competent. So that when they're approached by junior engineers or any other engineers who are working on a project that they're able to answer questions straight away and be able to resolve issues and be able to look at a project, step back and see whether the right technical solution or the solutions is technically correct.

I think the interpersonal skills are very important because you can have very technical people, who don't have interpersonal skills and unfortunately in that situation engineers will not be able to approach their managers or their leaders to be able to get those questions resolved. So there would also need to be a balance on that.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate, which gives you a sustainable professional advantage?

Response I think the benefit of our organisation is that, because we are such a large organisation with many different disciplines, that I think we try and elaborate as much as possible the knowledge and the resources of our teams in the UK and our specialist teams in the UK. And we have had numerous occasions, right now we're on projects where we're dealing with very complex for example mechanical and natural ventilation design solutions. We're leveraging knowledge of other organisations specialist teams in the UK who know how to deliver those systems. So that enables us to you know, be able to learn the skills efficiently by asking someone who knows without having to spend a lot of time trawling through information, trawling through technical data sheets, trial and error, you know, we're able to leverage the already available skills, knowledge within our own departments and our own companies.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response I think we spoke earlier about the difficulties with non-collaboration at design stage we'd end up with problems during construction stage. I've had numerous issues in mechanical and mechanical design, invariably if there's problems with the design, those problems in the design won't be found out necessarily at construction stage. But if it's relating to problems with heating or air-conditioning systems they invariably get found out at operational stage and that can cause huge problems. It caused huge problems for companies in terms of lost time due to employee discomfort or employee unhappiness, it cost the designers lots of time in spending time after the project is completed trying to solve problems and ultimately it cost money and energy and electricity wasted on inefficient buildings. So, I think specifically in mechanical you can have either issues that cause problems in construction but they can also cause issues at operation and then on the third end of that, is there's issues that aren't found in operation and will be - remain in the background all the time which can ultimately either cost a lot of money or cause plant failure.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multi-disciplinary design?

Response Absolutely, we would have experienced that problem and on building services particularly mechanical engineering in Ireland, it's very much the mechanical building service engineer covers a lot of different disciplines. Whereas you go to the UK there would be more specialisms and we're finding now that with the increase of new, much more stringent building regulation standards, much more stringent technical standards in various different aspects of the mechanical building services design, that it's becoming much more difficult for staff to be more generalised. And we're ending up by default having engineers, having to be specialised in certain areas. And I think that's just going to, I don't see a way out of that because of the level of complexity that's coming into various different aspects of mechanical building services design.

Question Nr 15. Technical coordination, in the context of building service engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work, in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing cooperation, is a major aspect of engineering practice.

Response Well, when you say willing cooperation I think, to me that means that everybody needs to understand why something is being done. So again that's a proper understanding of the brief, a proper understanding of the goals of the project and often, you know, particularly in coordination if you're asking somebody to do something and they don't understand why this needs to be done, that can often lead to frustration. It leads to too much time being spent on it and ultimately inefficiency.

So I think a major part of getting peoples' willing cooperation is to you know make everybody understand exactly why we're doing something as opposed to just telling someone you know this needs to be done, explain why it needs to be done, why it's important for the project and what's the benefit in the long run.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to coordinate all service design activities, processes and resources in building service engineering practices. What is your interpretation of design coordination?

Response Well, design coordination is, from the outset of the project is all multi-disciplines staying together, on a semi-regular basis and collaboratively coming up with solutions to technical and design issues with projects. It's an iterative process from start to finish that requires management and specific management of the process and relies on each individual discipline to take ownership of certain aspects of that coordination and report back on a regular basis, to whoever the design manager or lead consultant is. And tracking those issues as they are closed to completion.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40 - 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response I think it varies depending on the job and depending on the schedule, I think if a project is given sufficient time and sufficient resources at design phase, I think you can go a long way to resolving a lot of those design issues if a project is under a lot of pressure at design stage with very tight programmes, and insufficient resources. Then that is, I'd agree that ultimately those problems have to be resolved and they do become an issue. But I think if a project is, you know, if you've got the right people who understand the project, who understand the coordination issues, who understand you know the construction process and what a particular design decision might impact on the construction process and through correct use of BIM and software like that, I think that can be reduced.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomenon

Response I think we've had specific projects recently where, in large pubic buildings, where there's been multiple stakeholders that need to be consulted. And I suppose the building was designed, tendered and halfway through construction without the stakeholders being consulted. And ultimately those stakeholders did have their view and at the end of the day they were the ones who were operating the building, so whatever they needed had to be incorporated. And the issue is that if they had been, if the correct design process had been followed and those stakeholder had been engaged early and had been brought along with the process as they should have been, it wouldn't have caused such an issue but from a cost and time programme, cost and programme perspective, as it did during construction.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response I think so and I think that's why we try to copy as much as possible from design, when I say copy but use standard details or standard information or standard technical information that's it's available for a previous project. And bring that through to the next project, so basically lesson learned that from previous projects are used. I think, certainly from using the same, from what we use in here is a unified file index where every piece of project information, deliverables, submittals, it all has a place in the unified file index. So that everybody knows where the information is. So if we're trying to cross-reference back to projects and find information on previous projects. A certain piece of information from that project, we know exactly where we can find it when looking for it in the future and that can help.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are completed to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response I think my experience of building services engineering leading and managing the programme, is typically on large technical projects such as data centres because they're invariably mechanical, electrical building services led. My experience has been that they've been much more from a technical perspective, they've been much better co-ordinated because that engineer has an understanding of the technical approach and understands more so than a non-building services or a non-technical project manager would, exactly what an impact of one discipline might have on the other discipline from a technical point of view.

So I think from a coordination point and technical aspect, my experience of those projects where's there's been building services engineering leading them has been very positive. I would have recognised that those building services engineers would have less, would place less emphasis on other aspects of the project such as programme, cost and contractual issues and I think that is something that I would have noticed in those projects.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to step changes in performance. How is performance measured in your practise?

Response I think we do have three different, we would also have those three different levels of performance measurements. On the individual level, it's very much on a goals basis and less so on a project basis. So for peoples' individual performance on a project, while it may be taken into account in the overall performance management of that, a performance measurement of that person, there is no specific goals from a project perspective which can lead to and improve overall individual performance at the end of the day. That obviously will be taken into account but it's not that specific. On a project basis the metrics really are very much financial metrics in terms of profit, resources, there probably, certainly in our organisation, isn't enough recognition of the technical competence or the technical achievements or the technical measurements of projects. It's really or how you've delivered a solution, how that solution has been delivered in an energy efficient way or in a efficient way from a construction or operation point of view. It's very much measured in a financial metrics and likewise the organisational metrics are very much measured in an organisational way. Just going back to the project there are client surveys but again those client surveys ultimately can be project management based or you know, how the project was on time or on cost and again may not specifically recognise technical achievements on projects.

Question Nr 22 Early engagement between the client and technical design staff during the design process. In your experience, do you believe this communication correlates to the quality of design deliverable output?

Response It absolutely does, I think early engagement is very key to making sure that the client's requirements are understand, making sure that the client is aware of the various different restrictions of the building or making sure that the client understands who within his own organisation he needs to consult in order to get the correct answer. So, I think early engagement is key, we've had numerous experiences previously where late engagement with the client on various different requirements ultimately causes delay to the design process. And often times, it's too late in the design process to solve those issues and they get pushed out to construction which causes further cost and time delays.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design, so as to engage in a process of continuous learning?

Response Yeah absolutely, I don't think there's any other way, I mean you have to be a reflective practitioner and I think you end up being a reflective practitioner by default. Ultimately, when you make a decision on the design based on the information that you have to you at the time. If something, if you make a mistake or something goes wrong with that, you will always learn from that and the next time that happens you won't make that mistake, because you know either what information you need or where to ask for to get that information. So I think ultimately I would consider myself a reflective practitioner and I can think of various different examples throughout my career where I would have, you know, not done things correctly or done them as I should have or and I would feel I would have learned from that and had the exact same decision being made two or three years later that I would have done it very differently.

Question Nr 24 A successful building services engineering design entity achieves client satisfaction, provides technically sound professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response I think our qualities are our collaboration, definitely our design collaboration, the fact that we do have multidisciplinary people in the same office. I think that gives people the satisfaction that they know they can if they need to ask a question of another designer they just have to call over to them. I think we also get the fact that we have a large organisation with various different expertise and various different offices around the UK and Ireland and even worldwide. I think that gives client satisfaction because they know we have that technical ability available. It gives employee satisfaction because they know that we're able to - they have the resources behind them to be able to answer complex technical queries when they need to and I think that's a unique quality that attracts a lot of employee.

Question Nr 25 The use of design decision making tools, in the propensity of power emergency lighting, lifts, lightening protection, heating and ventilation, daylight simulations, wind and solar, may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response I think it varies in terms of quality, I would think a lot of more complex CFD packages that I've used in the past while they may be very accurate, any of these tools are only as accurate as the information that you put into them or as competent the user is in using them. So my view would be that with any of these softwares, simple is best, I think that's the most accurate results you can get when you start using complex software you really need to have ensure that the information is going into them is correct, the person who is looking after that software knows exactly what they're doing and what they're looking to get out of it. Because if that information is not available you may as well just be doing a simple calculation because you will ultimately get a more accurate answer.

Question Nr 26 Building Information Modelling is not just a fancy 3D model, it is about moving away from traditionally industry practise of producing multiple and independent paper based documents that describe what a building is, toward creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response. I think one of the main challenges from 2D to 3D modelling has been a time and cost challenge. Ultimately when we produce 2D drawings we were coordinated to a point and ultimately left a lot of the responsibility of final coordination with the contractors. By now designing in a 3D environment we can't do that anymore, we can't hide coordination issues they're obvious in a 3D model and that's ultimately meant there's a lot more time spent at design stage now in a 3D environment than there was in the 2D environment and that ultimately has a cost impact. And I don't feel that fees or design fees among consultants has necessarily gone up to reflect that, design consultants, particularly in Ireland have just absolved those or absorbed those time increases and it's just let financial and time pressure on projects.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time with more user friendly, flexibility, intelligent and parametrical user environment. How was your experience thus far?

Response My experience has been quite limited really because, as a probably more a team leader I wouldn't have a huge involvement with or spend a lot of time on it. I think probably for the engineers who would maybe design in Magicad - there's a lot of tools in there, in Magicad, that for say mechanical design that they are not using and possibly could. And I think part of the issue with using those tools is that if you're originating or designing those tools, whoever in the organisation is checking those designs, needs to be able to use the tool as well and that can often times cause a challenge.

Question Nr 28

Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design coordination between discipline leading to install-ability issues.***
- ***Poor communications, deficiency or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign.***

As a direct consequence of these deficiencies the impact in design consultancy practise is significant. The primary dysfunctions relate to professional dissonance between the M & E design engineers, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response

In terms of those dysfunctions, I think poor design quality is the main one that I feel we'd be quite strong in dealing with and we try to resolve that by following very strict QA procedures. And that's not just at the end of the project when the design is finished, that's you know in term designer views at various different stages of the project to ensure that any design issues can be, that don't go left unresolved until the very end. And by doing a final QA check, we ensure that you know we've done as much as we possibly can during the design to ensure that it's been coordinated and designed correctly. In terms of the programme and cost, I think it's to try and make individual engineers and technicians and everybody in the team aware of impacts that their design are going to have on the construction stage. Also impacts that their design will have on the design time and cost spent to ensure that people understand that the impact of their decisions, what that has at this stage of the project and the future so that people understand what the impact is, it maybe makes them less likely to gloss over issues and push issues under the carpet.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Senior Mechanical Engineer + BIM Lead, Raymond Reilly (Researcher)*
Date/Time	*18th December 2018, 9.30am*
Venue	*Project Site Office, Dublin*
Participant Nr	3 *(Senior Mechanical Engineer)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) ***the design and construction stage in the context of people, processes and technology, and***

ii) ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. Question number one, how would you best describe the building services engineering design process?

Response Yeah, so from my experience, it really varies from practise to practise the QA and QC, and the design process in each firm seem to vary widely across the construction industry. I don't think the building services design process is as streamlined as it could be when you compare it to other industries such as pharmaceutical. It seems to be more standardised across the board. So I think it's certain companies have better policies that others, but I think there's still a lot of work that can be done to streamline the design process in building services.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Yeah, so traditionally on design projects there's kind of a workflow, that is a common trend across a number of projects, in that the majority of the work seems to be done, I suppose at the tail end of the design stage of the project. Which isn't ideal because with time constraints and programmes, it can lead to inaccuracies in design information, rushing to get information out the door etcetera. So explain the professional trend ... so I think that the service, I suppose if a lot more work can be done on the early design stage, it would help with the quality in the tender documentation.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly technical, educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response Yeah, so from my experience, I suppose I can relate to this one quite well. So I don't think it's got anything to do with the degree, it's more down to the person. We're consulting engineers at the end of the day, so a lot of people seem to forget the word 'consultant', consultant means you're able to work well with people. So I think you can have all the intellectual capacity in the world and have the best engineering degree in the world, but if you can't deploy that in person or if you can't work with clients I think that will really impede you in progressing with your career.

Like from my own experience, setting off as a young graduate, I went off to Irish Institutes of Technologies and some of my colleagues went to some of the best colleges in the world, such as London University and Cambridge University. But I was able to excel a lot quicker than these people because I think it's a lot down to my personality rather than my academic background.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Yeah, so can I repeat that… So following on from, yeah, so I think I'd strongly relate with that statement, though I don't know what the exact breakdown on the percentages on financial success versus ability. But I think there's a considerable amount to do with your personality and development, I suppose the progression of your career I think is going to rest on your technical initiative and ability rather than technical knowledge.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response I suppose one thing that I could see being done is implementing more management modules on engineering degrees. I think that could certainly be of benefit to students, integrating project management as a trained module on a building service engineering degree is something that should help bridge that gap.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I suppose I somewhat disagree, that it's, you're either a contractor or a designer. My own background I worked both for a consultancy and a design build contractor. And the principles that you apply in design, whether you are working for a contractor or a consultant are quite similar. I don't think there's a social divide between the contractor or engineer, I've been involved with professional bodies like the Chartered Institute of Building Service Engineers, it integrates people from all different disciplines and backgrounds so I don't think, I don't see that as a major issue in Ireland anyway.

Question Nr 7 Design is a difficult process to manage. And needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects do not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah, I would agree with that statement, I think that the management of the design process is fundamental. You can have all the technical expertise in-house, but if that design process isn't managed correctly and there isn't adequate amount of time for design in the design programme, it can lead to several issues later on, in the project.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I'm not sure on the exact figure of 80% but I suppose there is, there can be a lot of rework carried out in engineering designs. I suppose I can give maybe one or two examples here. I work for, I suppose a more old school firm in my experience. And the manager wasn't even able to use Microsoft Word. So he had to rely on engineers to do admin tasks which was obviously a waste of time and resources. Another potential issue I see is that, the engineering is so rapidly evolving and changing, particularly in the last 10-15 years and a lot of it is probably to do with information developments, IT developments. So there's probably a bit of background mentoring required there, that guys with 30-40 years experience, you could have all the engineering knowledge in the world, but they might not be at the fore-front of modern design and building information management. And the likes of new policies coming into place. So it's getting, I suppose bridging the gap between guys that have that years experience but also the new guys coming in that have the modern experience.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining systematic management during construction. What is your experience? So, in short what we're saying there Keith is that your design process?

Response So obviously the design phase of the project is of fundamental importance to get right as it has a knock-on effect on the later phase of a project, which can be extremely challenging. Like I suppose a fault picked up at design stage is readily fixable and at minimal cost, probably just some co-ordination between the design team.

But when you get to, get on stage on site and you have a major issue that can't be resolved for maybe economic reasons, or technical reasons on a project, that can have a major experience. So I would agree with that statement that getting the design right and especially fundamental design, for life safety systems would be critical and it can have an effect on systematic management during construction.

Question Nr 10 Dissonance between designs in an multidisciplinary practise is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Yeah, so I suppose I can relate fairly strongly with that process. Particularly in terms of building information, modelling and things like that. Co-ordination is critical between each of the design teams and not picking stuff off the design teams can lead to several issues in the construction phase of the project and a lot of these can lead to cost to the client. Does that cover that?

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response I suppose for management, it would be someone that leads by example, has good technical ability but also has good interpersonal skills, can manage a team, is good at working with people and also can manage clients and client expectations.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practise is directly related to how managers can stimulate learning. A learning practise is in organisations skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate which gives you a sustainable professional advantage?

Response So, a couple of things we do within this - we have a number of structures, CPDs from industry specialists organised throughout the year to cater for the most modern trends in building services. We also have at our disposal a number of flexible learning platforms, such as degree.com, LinkedIn learning, Nord-Quest University. So that gives us the opportunity to learn at our own pace and kind of in our own time, I suppose formal training can be difficult to integrate into modern construction programmes. So being able to learn at our own discretion and time is a good benefit.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response So, obviously the early design co-ordination is of paramount importance. And if we don't have a co-ordinated design between each of the major disciplines, the MEP, the structure and the architecture, particularly, then that can lead to major issues at the construction phase of the project. So, this needs to be done by a number of design team meetings and coordination meetings in the construction phase - putting in as much coordination as reasonably possible at the design stage of the project to avoid further risk during the construction stage.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multi-disciplinary design?

Response Yeah, I suppose traditionally in construction the architect has always been a well known discipline, similarly with the civil engineer. But in building services it's probably seen as a bit of a 'dark art' because there are several different disciplines within building services. You've got mechanical, electrical, plumbing, sprinkler, just to name a few. I do think that in Ireland we seem to have a better approach than in other countries. Particularly as a building service engineer, you look at the broad spectrum of disciplines and have a good working knowledge. For example on the mechanical side, you don't branch out into plumbing or H-vac design, whereas in other countries such as Australia and Europe, you specialise in a particular area of building services. So, I think that's very important to be able to have a broad spectrum of understanding in future design in building services.

Question Nr 15 Technical coordination, in the context of building service engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practise.

Response Yeah, so I suppose the wider team need to understand, not everyone is at the forefront of the client interface meetings or at the brief. But if the broader team of engineers and technicians working on the project understand the overall objectives for the project, then that can lead to a successful design. If there's a lack of understanding of what actually needs to be achieved on a project then that can lead to issues. So a couple of things that can be done there is, have early stage technical review approach for the project and building information management reviews at early stage, to try and engage with the team and ensure a process works for going forward on the job.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to co-ordinate all service design activities, processes and resources in building service engineering practise. What is your interpretation of design coordination?

Response So design coordination would be, I suppose there's a couple of processes there. Just on a typical construction project you have your MEP engineer, your architect and your structural engineer. So, within each practise, you'd expect each discipline to carry out their own internal process and design coordination. So the mechanical engineer and electrical, all their information should be collated, coordinated, and similarly with the architectural and structural. And then a series of workshops should be carried out that integrates each of the design team's information into one platform, so that the multidisciplinary design coordination can be carried out. It's making sure that all the individual elements of MEP system and architectural and structural system integrate into one project and that the design is coordinated and works for the project requirements.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40 or 50% of the total work hours on a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Yeah, so I suppose it really relates to project specific. I do agree that when there is a lack of coordination carried out at the design stage of the project that there is, there can be considerable extra work required at the construction phase. And also a number of additional costs can be incurred by the client due to a lack of design coordination but where projects are ran successfully and is there is good BIM coordination and design coordination throughout the project, then the risk of problems at the construction stage can be substantially reduced.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomenon.

Response Yeah, so I think in general that engineering design processes are considerably lower resourced than in comparison to other industries. I think the construction programmes are always getting tighter and design programmes are always getting tighter, as the years progress on construction projects. So, it does lead to inaccuracies in design when there is little resources. A lot of this can be related to the fees on projects as well. That if there is low fees on a job the resources mightn't be there that would require you to achieve a successful co-ordinated design. So, achieving milestones or programme dates with a lack of resources or information would lead to a lot of issues during the construction phase of the project.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response Yeah, as far as possible I suppose we try to work off our own company's standard approaches for design. We do not try to re-invent the wheel. So, there is a number of platforms available to us within our own company to make sure that we kick-start the right processes to carry out the right quality auditing and quality checking procedures at various milestones. So we try to do that as far as possible.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Yeah, so my experience of this would be as a design manager working for a mechanical and electrical contractor, where we would have managed the design information for detailed design of projects which would have had input from several sub-consultancies and specialist design such as smoke extract systems and fire alarm life safety systems. So, some of the major challenges or objectives we had was relying on third party information and programmes.
So, we obviously always had dates to hit and targets to be met to achieve the project programme. But when we didn't receive design information in time for our third party suppliers, that was a considerable risk and left the company exposed in several areas in delivering milestones on the project.

Question Nr 21 Performance management provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practise?

Response So, I suppose on an individual level we have our own goals and targets that we achieve on a personal level throughout the year, they are measured by our managers within the company. On a project level, obviously each project would have a design fee that we have to work to and achieve certain deliverables based on that fee, for issue of information. So on a project level, if a project is going well, obviously you'd have the fees on track and the resources required for the project are met. Where a project may not be going well, we could be behind on dates and get negative client feedback, or we could be losing money on a project. So on an individual level, it's our goals for the year. And on a project level it's I suppose it's the KPIs of the project. On an organisational level, I suppose we look at the broader, the broader spectrum on each individual department, on how they are running overall. Obviously there may be poor individuals or great individuals, or poor projects and great projects within each individual team, but overall, that department or organisation might be running well or have performed poorly. So I think that describes how it's measured in our firm.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design deliverable output?

Response Yeah, I think that client interface and understanding the client requirements, is of paramount importance to achieve the quality of the design. It just means that having that coordination period and that collaboration between the client and the designer that both expectations are understood for what needs to be done, to meet the client's requirements and the designer can make sure that in his design, that the client expectations are achieved.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response I think I would consider myself as a reflective practitioner. I do try to take the lessons I've learned from previous projects to new projects and I do try to keep up-to-date with the most modern trends in the industry in both service engineering and integrate those into my design.

Question Nr 24 A successful building services engineering design entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe continue as a successful working environment.

Response Yeah, I suppose a major requirement, I suppose to be able to deliver a successful project is having the right people around you. So like, we do have a lot of strong people on our MEP team that we can rely on to get work done and delegate work to. And being able to hand information over to certain individuals and expect that quality to be achieved really supports projects and delivers successful projects and obviously keeping client satisfaction.

Question Nr 25 The use of design decision making tools, in the propensity of power distribution, general and emergency lighting, lifts, lightening protections, heating, ventilation and daylight simulations, wind and solar energy etcetera. may be useful for guidelines. In your professional experience how accurate are decision making tools in your specialism?

Response In my experience it would be mainly to do with mechanical designs so for H-vac, ventilation and day lighting and sustainable analysis. So, we tend to use a lot of specialist design software, that can give a lot higher degree of information than can be done via a steady state hand calculations. However, it is good practise and we always try and reinforce to our team that there should be certain QA checks carried out on using specialist decision making tools. So if we were to use this software, it would always be good practise to verify data via hand proofed steady stage calculations.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practises of producing multiple and independent paper based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response. Yeah, so I suppose building information modelling in Ireland is still relatively new on the scene. I think it's probably 2014, probably started to really set a trend on some of the major consultancies and construction firms in Ireland. But prior to that it was probably only 2012 that it was probably first being used in practices in Ireland. So, I suppose throughout my experience I've seen a number of challenges from 2D to 3D. I suppose firstly, it's the older generation of engineers and technicians that many of them have come from drawing boards and I suppose 2D hand drafting and already made the process from drawing boards to CAD. And now we're expected to make the process from 2D CAD to 3D modelling. That is a particular challenge and in my experience to date, with these particular individuals they are really struggling to make the transition from 2D to 3D modelling. Another factor I've seen as a major issue is the knowledge gap between technicians and engineers, or sorry mainly between technicians drawing and the engineer requirements on a project. Being able to model in 3D requires an engineering knowledge on how systems can be built. It's not just a case of drawing lines on a screen anymore, you really need to, you need engineering and technical knowledge of the sytsem being modelled in order to carry out the process. And also I would think there's a good degree of backward mentoring required on building information modelling, as it's so new on the scene. I think it's mainly the younger generation of engineers that seem to be the most up-to-date on the subject, and it just means that I suppose the senior management within companies need to acknowledge that there is a learning gap to be bridged. To update senior management on the new innovation model.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexible, intelligent and parametrical user environment. How has your experience been thus far?

Response So, I think Magicad is a powerful tool to have within a building service consultancy and the family elements, or the objects for, within a 3D model and for specific pieces of equipment, they can be very time consuming. So being able to have Magicad family data for specific items and equipment within the software, can lead to considerable time savings on a project. If you are to carry out modelling of bespoke equipment of families without Magicad it would lead to an extra considerable amount time to be spent carrying out this. But I suppose outside of the 3D model itself, there's a lot of parametric data that's included in most manufacturer's modelling. This relates to asset management and [00:31:48.5] information. So being able to have that data within each manufacturer's equipment can lead to further time savings, not just for the 3D modelling of the element but also on that information that's integrated into each family.

Question Nr 28 Final question. Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design co-ordination between discipline leading to install-ability issues.***
- ***Poor communications, deficiency or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign***

As a direct consequence of these deficiencies the impact in design consultancy practise is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response I suppose on any project there will always be some issues, it's probably unrealistic that a project will run as a well oiled machine and there won't be some issues encountered at the constrution phase of a project that will probably lead to some element of redesign or redesign of programmes. However, it would be good practise to always carry out a lesson learned approach on previous projects, keeping a register of lessons learnt within our organisation is something that [00:33:43.5] does. And before we move onto a similar project of scale and complexity, it would be good practise for us to review the lessons learned register for previous projects of this nature. And to try and ensure to the best of our ability that the same issues do not arise within these projects.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Project Mechanical Engineer, Raymond Reilly (Researcher)*
Date/Time	*20th December 2018, 11.00am*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	4 *(Project Mechanical Engineer)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Building Services Design Process, well it starts in stages and it's sort of from a more conceptual stage to a more practical, detailed stage. It involves extensive coordination and collaboration with different design teams. And obviously the coordination, multidisciplinary coordination between mechanical and electrical. And now more so because of BIM, extensive coordination with the physical, from a physical point of view, what she can fit into a building and ensuring that what you're designing can be practically built on site in a safe manner.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Yeah, so that really relates to a trend when you have legacy work. So, obviously work that's been designed by someone else, coordinated by someone else and all the information has been with that person hasn't been communicated effectively to anyone else in the team, or there hasn't been a good proper handover process. It happens when say the project manager deals with the frontline and doesn't necessarily communicate clearly with the rest of the team either what deadlines are, or what the scope of work is, or what is agreed or that what is actually agreed with different design teams is actually doable by the designers, etcetera, etcetera. So all of this means not having enough time to design something properly and either leaving issues unresolved and having to issue it when the project starts or trying to push the accountability on different design parties, which is just as inefficient as anything else.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response I think if you study engineering, you will be taught the theoretical aspect of the job, which is obviously very important. You're not going to be taught the management side of the job which is an important quality to have when you're working in this industry. And mainly organisational skills, communication skills, management skills in general, agreeing on deadlines, understanding scope of work, understanding what is and isn't a cost change and if it is, how do you communicate that effectively? How do you negotiate with a client either for time or for a variation and what not. So, we're definitely not trained and I don't know of any good programme that trains people to do this. This is something that every engineer, who has an interest in progressing in their career needs to know and it affects the rest of the quality of the design. So I suppose that's what I would identify as a potential improvement for academia to produce better graduates.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your professionalism.

Response Yeah so, we will have, if we work with a team of very technically trained engineer, it doesn't, you won't see the quality of it unless that team is managed properly with, you know, with adequate timelines, with a clear scope of work, with a clear understanding of who is accountable for what. And if no one, if there are grey areas where it's not clear that it's clarified at an early stage. And that a person with adequate training and understanding of the complexity of a problem can resolve that problem. So, being specialised in something and being very technically trained is very, very good. But what's more useful is to have that one person who has the capability, the personality, to communicate with a team and to lead that team to design a project, you know, at good quality. So, that's how I see it explained in my team.

Question Nr 5 As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response Obviously training helps but I think training helps only 20%, it's really, we're kind of learning the job on site but this, like you could be told this is the process you need to follow, in a very academic manner. You can have even a checklist but really a lot of those things are moving variables within different teams, and it's just having that personality that allows you to keep track and see a problem when there is one, see when something is not clear, raise the question. I think a project manager is never expected to be an expert in every field but he is expected to ensure that everyone is clear on what their scope is. And if there are things that, any work or any action that hasn't been taken by anyone, he is expected to raise that issue and ensure it's going to fall on someone's shoulder. So, I've learned it on the job personally and I know that I've had trainings but I haven't found them to be excessively useful. So I don't know, aside from mentorship is very useful, someone who can give you, a project manager who has gone through the process himself or herself to tell you how it needs to be done and what you need to look at. But no, it seems to be more of a trial and error process.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response Well personally, I think if you're a good designer on a good design it doesn't just work conceptually, it works concretely, it works practically. I think like things like BIM aim to cross that boundary between a conceptual design and a concrete one and a practical one. Now, I think in terms of how we communicate with contractors, I've always seen it in every project I've worked there is always a 'I scratch your back, you scratch mine' kind of mind set. Most contractors are trying to be helpful on site, they're not all helpful but they are trying to be helpful and bring a project to completion. And so you know, as long as engineers we understand what is their view, what is their complication and how to build something and why they're having this complication and how we can help them to do things in a safe manner, in a practical manner, we should try to the best of our knowledge to do that. Obviously we shouldn't do work for free so we should learn to know when it is the contractor's responsibility. One thing that I've found useful now it's a bit getting into the details but method statements and reviewing method statements. That helps engineers who don't know how it works, it's supposed to be done to understand how a contractor would see it done on a step by step basis but also from a contractor's point of view seeing that we're actually interested in reading their method statements and making comments on it, it kind of reassures that we are, you know, also working as a team in trying to again build something in a practical and safe manner.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah, I completely agree with this, this is why I don't believe AI is going to take our jobs anytime soon, because it's not, like I've worked on a steam project and steam systems can be presumably a bit complicated. But because it was just one party, we didn't have an architect on board, there was no structural works or anything, it was relatively simple. When you start to look at say a train station, an underground train station, having to deal with major civil works, structural works, architecture, fire, fire is a big one as well. And obviously all of the services that go inside it and electrical especially there's an extensive amount of services in it. Because of that there's so many different parties, all of them having their own agenda, their own concerns on the design. It becomes very, you know, the overall project can become very complex and this is where you need to have a lead that is extensively multidisciplinary and has extensive experience on those specific kind of projects to keep every single individual of every team and discipline in line in the scope of work and the client's requirement.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Yeah, so assuming that 80% waste means work we're not getting paid for, I think a lot of that comes back down to the scope of works and tracking changes when they do occur. And obviously having a good lead, with good communication skills, to tell the engineers when they should be doing the works, when different variables have been confirmed. Now we all understand that you know there's always an iterative process in any project. But we have to limit that to a reasonable level of iteration. And so we have to agree on for instance frozen models from with architects, we have to prevent continuous change throughout a project. And we have to be clear with different parties as to when they should be carrying out their task and only to do so when they have all the information they require to carry it out.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining systematic management during construction. What is your experience?

Response Definitely, especially on alteration works where there are existing services, commissioning as well is a big one and general coordination issues and finishes to be agreed with the architects for instance. It is, I think it all comes down to how much does a client value good services from a building services point of view. Having worked in Singapore, I can say for sure clients don't value that as much as they do in Ireland, so it comes down to - well we get documentations that are maybe 80% correct and the 20% we hope for it to be resolved on site. So, if the service is valued appropriately like I know data centre clients obviously you know value our services much more than they seem to value architecture because, you know, aesthetic is not really an issue in data centres. Then I think this management can be, this management issue especially relates to building services can be overcome but if we're not valued appropriately then that's a problem we're just going to have to face.

Question Nr 10 Dissonance between designs in an multidisciplinary practise is often brushed under the carpet at design stage. How do you relate to this phenomena?

Response It's consistent with all the projects I have ever worked on, it's just that it starts with having to, for any engineer who is very technical to have to explain their problem in a layman terms to different members of the design team. To communicate adequately why or how this issue can be resolved but what are the consequences. And to find a solution that is agreeable with all members of the design team. It is often brushed under the carpet at design stage because I think every member of every team, especially if they don't have a project manager who is heavily involved, tend to feel accountable only for their own portion of the design and they don't feel accountable for the coordination bit that needs to be carried out.

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Management is person who again understands scopes of work, understands, perfectly able to delegate tasks and delegate them effectively and agreeing on deadlines that are reasonable and achievable. But at the same time, not to long for people to take an extended amount of time to do the work. Someone who has a good understanding of how long a person needs to carry out a work. It also means, sometimes it means concealing some information to the design team, not telling the design team that, you know, we had an extension for the deadline, getting them to do the work while following, you know, an earlier deadline which gets them to work potentially more effectively.

So, it's understanding the limitation of your team. It's also not, you can respect your team but that doesn't mean like you can trust some members of the team and not fully, keeping in mind that a person needs to be told to something for them to do it. It is not assuming that this person is fully aware of what they need to do. So, great communication skills and again, being multidisciplinary in my view helps, it doesn't mean being an expert in every discipline but making sure that every member of each discipline knows what they have to do.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practise is directly related to how managers can stimulate learning. A learning practise is an organisation skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate which gives you a sustainable professional advantage?

Response I would prefer the formal method mainly because it means someone is taking accountability for what they're teaching me and it has to be right. That is the point of a, you know, a CIPSI approved, CPD course for instance. So that means everything I'm learning I know has been checked by someone. Informal learning is fine, it's great, but I think sometimes communication - miscommunication can mean you're not learning the right thing or you misunderstand what you're learning. Especially when it comes from for instance from suppliers you know, there's an agenda behind, you may not be aware of that agenda so you can't be sure of how accurate the information you're learning is.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response Yeah, I think it comes down a lot to cost. So if a job is costed appropriately and obviously if it's managed appropriately and all changes mean there's going to be a variation. It means people will not feel that they have to limit the amount of time, unreasonably, to get a task done properly. It also means that the lead designer is going to feel more free to set up different coordination meeting with all members of the design team without feeling, you know, this is going to impact their budget greatly. So, lack of budget in any project leads to that kind of dysfunction and more RFI construction stage means more work that needs to be carried out. And so it's a bigger cost to the project again. So, you know I find, I've always found that spending more time and money at the start of a project means that it makes our life easier, obviously during construction stage and it means less of a loss and a much easier way to control for a cost management throughout the project lifecycle.

Question Nr 14 The increasing number of specialisms in the building services engineering design process, results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yeah, so an example of that for instance in Ireland is nZEB like I've heard of people looking for an nZEB specialist. But nZEB should supposed to be everyone's speciality because it's a building regs compliance issue. So anyone who doesn't comply to it, their design just is in non-compliance with the law, with the regulations. Personally, I always feel I should be multidisciplinary, I started off doing fire safety engineering and now I'm in Ireland doing energy. I would feel responsible when I see a mistake on an electrical package for instance. It must be taught this way, like I fully appreciate the fact that there are some designs that are so intricate and specialised that you do need to have a specialist to look at it. But that's not the majority of our work, the majority of our work involves us being coordinated and multidisciplinary. And it's more accountability, again I feel it's more in the mindset, people have to feel that they're just as responsible for their work as they are for the other team's work and if they've raised an issue at least they've raised it. If no action has been taken at all and they can't seem to get any collaboration that's a different problem but at least they have to raise it and feel that it's also their problem because they're part of this project.

Question Nr 15. Technical coordination, in the context of building services engineering, means working with and influencing other members of the design team so, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing cooperation, is a major aspect of engineering practise.

Response Yeah, so it's I mean BIM again is something that ties into this because it's a live technical collaboration method of working together in a team. So, a programme is obviously where you start, I think is where we all start with deadlines, with agreeing when frozen models are actually frozen and whatnot. There's obviously a degree of, you know, the team you're working with has to be reasonable but also has to understand why those deadlines have to be agreed in advanced, much in advance and why it is important for us to be able to resource the work within our team.

So there's a degree of, you know, we want to agree to a deadline that's obviously reasonable with everyone but we have to understand that everyone is working in a different team that has a different dynamic, different managers, different level of resource capabilities. This is always, you know, there has to be just a good amount of flexibility but at the same time deadlines have to be agreed for it to be done.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to coordinate all design activities, processes and resources in building services engineering practise. What is your interpretation of design coordination?

Response It's multidisciplinary. So it's understanding everyone's concern agenda, either if it's for the QS, for instance it's concerned on a contract, if it's the architect it might be aesthetics. If it's the fire engineer it would be safety, escape routes and whatnot. So it's the capability to understand everyone's potential concern for the impact that your design is going to have on their design. It also means regular meetings as a design team to discuss, because there's only so much you can do with email correspondences and sometimes you need to have everyone in a room to be able to agree on this.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40% - 50% of the total work hours on a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Yeah, I would fully agree, like we're not, we don't expect ourselves, I mean at least from most of the cost plans that I've seen, we don't expect ourselves to work as much during construction stage but we always do if we haven't spent the right amount of time during the design stage. So, all I can do is agree with that statement.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomena.

Response Yeah, so again it comes back down to understanding your scope of work, your programme, but also what is it that you need to know. I think different and trained engineers, graduate engineers sometimes want to agree on a deadline thinking that they can achieve the deadline not necessarily understanding the different variables that need to be agreed on first before proceeding with the works.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response Yeah, so I definitely would have a series of projects that I have kept, that I've worked on, that I have from different companies at different times. That I would look back on to roughly get a grip on what I had done at the time and why I had done it and to refresh my mind on a system, for instance. I definitely think you actually learn a lot from, I wouldn't say copying but at least checking different projects and understanding how different projects are doing and essentially not reinventing the wheel.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Well I mean, I'm going to have a biased answer but obviously from my point of view, when it was a building services engineer leading the programme, it felt like things were going a bit more smoothly. The fact is, like most of the jobs I worked on, they were either led by an architect or by a structure and it's no - I think I underestimate how much coordination needs to be done between these design teams. But I suspect that when it is led by a building service engineer and the requirements from the architectural structure isn't as intense, it should be, you know, the project could be managed smoothly enough.

Question Nr 21 Performance management provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to step change in performance. How is performance measured in your practise?

Response So, I suspect that most of the time performance of a project is measured upon the quality of the outcome and also how much time and money was spent to deliver that outcome. So it's having the right measure for both.

Question Nr 22 Early engagement with the client and technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design deliverable output?

Response Yes and no; we never want to have a client who says constantly 'Well what do you propose?' We would love to have clients who actually know exactly what they want and we just deliver it. And if there are obvious changes that's fine but they agree that that's a change, it's going to take more time and obviously a cost change for it. I think an early engagement can be problematic when you're dealing with a client who doesn't really know what they want and also seems to want to have their cake and eat it as well. It also means that as you go along and you start submitting, you know, your proposals they could, you're giving them an opportunity to flip, to change their minds along the way and to have you redesigning the works. And again if it's a client who is not really on top of things and who didn't really have an idea of what he wanted in the first place, it's hard to come back and say 'Well this is going to cost us more money and more time'. Because he's going to come back and say 'Well I didn't actually, you know, I don't think that your design was really in line with what I had asked for'. But then what he might have asked for wasn't exactly clear to the design team. So it depends a lot on the client essentially.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design, so as to engage in a process of continuous learning?

Response Yeah, I definitely consider myself a reflective practitioner, I think everyone should consider themselves as a reflective practitioner as well.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe continue as a successful working environment.

Response Yeah, okay. I think AECOM does, definitely is concerned with client satisfaction. We do have a QA-QC process in place for us to provide a technical sound approach that's been approved by different engineers, that would have been chartered and that are, you know, sufficiently trained to make that judgement. In terms of maintaining a supporting and rewarding working environment I suppose, you know, AECOM has a process of appraisal on a yearly basis. You're always open to speak to your manager one-to-one and to raise your concerns if you have any, so you know, it's a very inclusive team.

Question Nr 25 The use of design decision making tools, in the propensity of power distribution, general and emergency lighting, lifts, lightening protection, heating, ventilation and daylight simulations, wind and solar energy, etcetera, may be useful for guidance. In your professional experience how accurate are decision-making tools in your specialism?

Response I think they're very important at the very, very early stage. And then they quickly kind of fall through the cracks as you get along with a more detailed stage. But if I've learned anything is that if you get things right and fairly right at the first stage, first design stages, your job is going to be relatively easier along the way, at least there's going to be less hassle for coordination and whatnot and reiteration of the design.

Question Nr 26 Building Information Modelling (BIM) is not just a fancy 3D model, it is about moving away from the traditional industry practises of producing multiple and independent paper based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response One of the challenges is to get everyone on board. BIM is, it can be incredibly simple and useful when every member in the team is able to use it. And it can get extremely complicated when say maybe the lead designer of the project is not able, is not really BIM ready. So, that's a start having every member of the team BIM ready. The second one is having your client to be BIM ready. Simply because, if they're continuously your works on 2D, they don't necessarily appreciate the works that you've done in 3D and the value of that work. The other challenge is communicating a 3D idea, a 3D design into a 2D drawing. Because at the end of the day as far as I know, we're not getting contractors to price a job on a BIM model, we're getting him to price it on a 2D drawing, PDF usually. So that's also a challenge I think for young designers who are working straight on BIM, they tend to underestimate the amount of information that really needs to be in a drawing for their idea and for their design to be effectively communicated to a contractor.

Aside from that, I suppose the process of continuous change it's harder to manage on a BIM project because it's not longer submissions with frozen CAD drawings anymore. It's this continuous changing model and it makes it a bit harder for every member of the design team to track the different changes that have occurred from different parties and it means a lot of abortive work in the coordination process as well.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time, with more user friendly, flexible, intelligent and parametrical user environment. How has your experience been thus far?

Response Mostly positive, I do appreciate that tool, I do think it's very useful. I think the problem is maintaining control of your deliverables and the quality of your model. It's a bit like you know if you're trying to deliver a model that has a families that's been built and assessed by a different company, how do you ensure that you're in line with the quality of that product that you are using in your own model. So I think there's still a, as a designer you still want to maintain control over the end product and I think Magicad is taking that opportunity away but it does help with improving productivity and working in BIM.

Question Nr 28

Final question. Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design coordination between disciplines leading to install-ability issues.***
- ***Poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign.***

As a direct consequence of these deficiencies the impact in design consultancy practises is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response I think different approach has been taken at different, on different jobs and at different stages. Like there is, obviously these consequences which are coming from lack of coordination, communication, etcetera, it's all those deficiencies, that happens on every job. There's always going to be an element of time delay, that's the worst case, obviously additional costs and redesign that happens on every job because things get slipped or there's been miscommunication. And I think when it's happening extensively on a job, what seems to happen is just, on an ad hoc basis - not even ad hoc just this constant redesigning and researching and relooking at problems. I personally don't think the organisation can deal well with those dysfunctions aside from just answering RFIs and trying to resolve things on site. But it will always have the implication of time delay and additional cost. There's no, I just haven't seen it to be done well on a project that's gone bad, it seems someone just has to bite the bullet.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Electrical Engineering Lead, Raymond Reilly (Researcher)*
Date/Time	*17th December 2018, 4.00pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*5 (Electrical Engineering Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

- ***i) the design and construction stage in the context of people, processes and technology, and***
- ***ii) the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response I would describe it as a combination of design, installation, operation and monitoring of services for a building.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Well, there's a couple of things here. The first one is when there's a lack of information that sometimes result into a not proper design, also sometimes when there is a lack of time, which can be lack of time for the design, lack of design for checking a product so that can result in failures. Those failures are, then have to be picked up during installation and that can be very costly, because in my experience that can be costing three during the design, cost 10 during installation and can cost 20 if it's picked up after installation.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response Okay, first of all I haven't graduated from Ireland. I got my electrical diploma but I can say that with my experience of the people in Ireland is to do with a maybe a bit of practise, like being hands on, on things. So I don't know if it's part of the course that they can actually go and foresee installation, just small little things that they can understand actually how cables are laid, and or for example how actually a panel look like. Sometimes graduates don't even know how a distribution panel look like, you know, never mind asking them to design one.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your professionalism.

Response That's very true, very true statement. Generally in building services but not just building services as a discipline but in building services, yes, the technical knowledge is a small part and the design is actually a small part. But to get over the line a project is actually due to management, it's to individuals sometimes, it's to a team, how the team leader or the project in charge, the lead engineer communicate to the subordinates.

Question Nr 5 As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response Generally through further learning. In my experience like I went back and did a college course to learn how to do, not just a part of engineering but also the business side of it, because there are quite a lot of things that are project management. So, it's further learning would be my answer on that.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response That's connected to the question I believe number two, where the design generally is very, is not tangible. I think. Whereas, for a contractor it is very tangible because he's actually told he has to make it work. And sometimes there is a bit of a, this link is not very well connected between the designer and the contractor. It's possibly, as I said, if a designer get more involved in doing installation and commissioning, it may be beneficial to learn and you know, understand very little details of installations.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah, well the, what comes to my mind is this thing in this case is that the scope versus the reality. So sometimes it's not very clear what is actually the scope and what actually the client is expecting to receive at the end of the job. So the, so what happens is that when doing design there's no very clear scope, and that can create difficulties, delays in how actually the project should be delivered.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Yeah, I do agree with the statement, I'd say that there should be better planning. Maybe more focused meetings and also the right resources should be allocated to the tasks and generally a review of during the design as a process should be done.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining systematic management during construction. What is your experience?

Response Quite an odd question. Okay, can we do that at the end maybe?

Question Nr 10 Dissonance between designs in an multidisciplinary practise is often brushed under the carpet at design stage. How do you relate to this phenomena?

Response Yes. That's yeah, sometimes time actually plays a big part in this. Sometimes when there's a different discipline involved in the same project, we for example, need to get the right background to do our design and they might update, you know, after we've done our design. So, it's to do with co-ordination and timing that, that's something that needs to be addressed.

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response In building services management is, has to aspire, guide and create a team that actually works very well together. The, it's important that the leader is part of the team, he give a clear guidance of what is actually required, he gives the right time to perform a task without being too hard on the subordinates and being understanding if they do need things outside of work, you know sometimes people have, you know, so.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practise is directly related to how managers can stimulate learning. A learning practise is an organisation skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate which gives you a sustainable professional advantage?

Response That's a very tricky question. I mean it's very hard to learn doing a project because obviously it slows down all the process and retaining that is also very difficult because - and transferring that too. So, it's time consuming to teach your, the people who work with you what you're trying to achieve but at the same time, it can have their benefits, you know. So it's very hard to actually achieve that.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response It's quite a little similar to the question at the start. Yeah, I believe that the inefficiency that can develop from the design process is to do with the information prior to start, a proper healthy start before the design start. And also to do with, you know, put the right resources in the right place. Sometimes also some difficulties comes when people are side tracked from what they are trying to do all day, trying to do above what is actually required. Sometimes the scope is very clear, people tend to deliver something above the scope that can be inefficient**.**

Question Nr 14 The increasing number of specialisms in the building services engineering design process, results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yes, we do, that's very true, what happens sometimes, people tend to actually specialise in particular things and when that person's not there the, all the process seems to actually go on hold. At the same time it's very hard to get somebody to know everything about anything. So it's maybe like trying to get the people that have certain specialities, specialism, to pass it on to graduates or project engineer, just to keep things moving.

Question Nr 15. Technical coordination, in the context of building services engineering, means working with and influencing other members of the design team so, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing cooperation, is a major aspect of engineering practise.

Response Yeah, as an electrical MEP engineer, one of the biggest challenges sometimes is to co-ordinate with a structural engineer or architect and also coordinate with the non stop changing to design. And it's very important to create a design freeze where we all agree that there's no changes for the time being, we go ahead with the agreed package for example, for tender and then once tender is agreed we can review all the changes and resubmit the final construction package.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to coordinate all design activities, processes and resources in building services engineering practise. What is your interpretation of design coordination?

Response Design coordination is when all the different disciplines, they actually talk the same language. What that means is, that if something is changing, everybody is aware, everybody knows who's going to be acting upon that change. So the result is that everything is co-ordinated. There's no need for, for example, if it's just moving a wall, that there's no service in that wall that an MEP is involved in this change. You know it's just, and also the same meeting, sometimes meetings tend to be too long and full of people that don't actually have any active part in that.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40% - 50% of the total work hours on a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Yeah, no I had a big experience on this like in all my previous jobs. Like, what happen is the scope is not very clear, there's also, you know, because time is important, the package has been issued in a rush and not proper checking took place. So yes, it's very costly to rectify something at a later stage if the only option is to take the proper time but it seems to never be the case.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomena.

Response Yes, sometimes, like can happen in our organisation, where we didn't have any input into the bidding process. And sometimes the QS look at similar projects and things and take the assumption that it's going to take the same time to deliver a similar type of project. But the information is always change, it's different from job, from project to project. There's no same project so things are different, clients are different, information flows differently, and also now with the inclusion of BIM modelling, that actually is not being taken into account in 2D design process properly.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response Certain aspects yes, you can go back and review what's done before, but technology is ever changing. For example LEDs in the last five years, you they took over the rest of lighting so, it's a bit of both. It's a bit of both process.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response It depends, it depends on the size of the project. You know, small projects are very easy to keep on track. Because it's the factor that affect the process are very small. But a big complex project, sometimes it's a combination of lots of information, stakeholders, client requests and so it's, it depends on the size of the project in my experience.

Question Nr 21 Performance management provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to step change in performance. How is performance measured in your practise?

Response Well firstly, performance is measured through deliverables, generally there's not much time to actually see anything above that because it's a very fast paced environment. So, unfortunately it should be a combination of a lot of factors, but generally ended up to be just upon deliverables.

Question Nr 22 Early engagement with the client and technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design deliverable output?

Response It does. It does greatly. Generally when we actually engage with a client, a client is actually engaging with designers a better design is always a result. Also, as I said, when the expectation of the client is actually are reflecting to the design but, you know, if all the information is provided and the client is clear what he wants that is delivered faster than any other type of project.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design, so as to engage in a process of continuous learning?

Response For myself, yes. I'm generally very flexible on, I never think the designs that I, I've done that before, I know everything. And so there's always a way of learning new things and put yourself on the line and ask, very important, ask for help or just a consideration to your peers to see if you're on the right track

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe continue as a successful working environment.

Response Okay, I'm just quite new here, so I know people very little, but I do know that some of the people working here has particular abilities you know, they can be very thorough. They can be, they are hardworking people, others a bit less but generally speaking I can see that they can contribue to the success of the project in different ways. Like some people tend to be more technical, some people would be more practical which is important because you need to have a combination of both.

Question Nr 25 The use of design decision making tools, in the propensity of power distribution, general and emergency lighting, lifts, lightening protection, heating, ventilation and daylight simulations, wind and solar energy, etcetera, may be useful for guidance. In your professional experience how accurate are decision-making tools in your specialism?

Response They are good help for the design as well, but though I recently have a, I got to an opinion where people should be, should know actually how to do those things without using tools first. Using a cable calculation programme without knowing actually how the former works, it's a little bit counter productive to the person because he doesn't know all the factors, all the variables that actually can make a better decision, even just inputting the right data, you know, from the start.

Question Nr 26 Building Information Modelling (BIM) is not just a fancy 3D model, it is about moving away from the traditional industry practises of producing multiple and independent paper based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response There's a - 3D modelling is actually, it's very useful especially when we try to understand how actually the building looks, it's very hard to understand the different level to add to the drawings. At the same time though, the amount of input required to get this to work is very high. It's definitely a way to move forward, but at the same time it requires that the people are better skilled to manage that. But is actually a very useful tool too for design.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time, with more user friendly, flexible, intelligent and parametrical user environment. How has your experience been thus far?

Response I'm not, I never use Magicad myself but I am really aware of the potential of improving the design. Yes, I can see this, like we moved away from draughters table, to CAD and now this is the next step to, in using more intelligent tools that they're trying to remove, kind of time wasting into design but at the same time we need to have people very well trained to use these tools.

Question Nr 28 Final question. Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design coordination between disciplines leading to install-ability issues.***
- ***Poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign.***

As a direct consequence of these deficiencies the impact in design consultancy practises is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response Well it's, we, it's very hard to actually give an answer on this because we are very particular time now especially where we, you know resources are not available, so we have to make the best of what you got and sometimes that's not the right way to do it. But it's unfortunately people are moving very, quite a lot across jobs, people move from one company to another company, and it's hard to retain their knowledge, hard to retain their experience. And therefore you, most of the time you try to restart again and all these deficiencies actually appear all the time into the design and how you like how you can deal with this, it's very hard, it's trying to incentivate people to remain, trying to reward people, trying to keep the the right training, and trying to engage with them if they want to further their careers.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Senior Electrical Engineer, Raymond Reilly (Researcher)*
Date/Time	*18th December 2018, 11.00am*
Venue	*Project Site Office, Dublin*
Participant Nr	*6 (Senior Electrical Engineer)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

iii) the design and construction stage in the context of people, processes and technology, and

iv) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Me personally, I would describe the building services industry – the design process is a number of factors. You've obviously got the drawings, the specifications, but also, I'd like to base this on communication. Communication is key I would say with the client, with the team members in the design. But also, with the contractors on site. I think that is a key thing. Basically, that was it on number one.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Basically, that's a fantastic question. Basically, in my opinion, unfortunate events in building services, it's a race to the bottom as far as financial aspects go. And a lot of things get rushed out in the industry to meet the clients demands and a lot of things are missed. And the reputation is basically that this will get sorted out on site. In my experience, I think that is a bad way of looking at things. On site, we are sort of against timescales just as much as when it's in tender stage. And a lot of things can be rushed, and I don't think the client gets the best value for money. I think personally we should be expressing our needs to the clients and asking for an extra week if we believe that things are missing, or we believe that things could be checked a lot more thoroughly. Although the client might express his concerns about not meeting a deadline, I think this is massively important because as we get to site, and things are like, oh, we'll just sort this on site. I think it causes massive problems to the programme, it causes massive problems with cost, and at the end of the day, I think the full construction and the client suffers.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response Having been brought up in England instead of Ireland, I can imagine it's very similar. I came up from a – basically an apprentice background, not a graduate background. I've seen many graduates come into the industry, and I still believe they are still not trained as well as they should be. Basically, they came in as academic fantastically well, but as far as site knowledge and communications, I think that is a big problem within the industry and I believe that things like site experience, it was part of their graduate scheme at university, is key in their development and I think that's something that should be looked at more vigorously in Ireland and England.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your professionalism.

Response Again, I think that's another fantastic question and to start that, I was quite surprised that when reading these questions. In my team, we have a good mix really. And I think a team – it's vitally important to have that mix. Personalities can differ. It's always good in a team to have a technical background. Some people you can go to who are really good on the regulations, but necessarily aren't always the best in front of a client. So, I think it's very vital that the engineering team have a good mixture of people. Someone you can take who's very good at communication, but also someone who you can take who's very technical. And I think that is absolutely vital in any team.

Question Nr 5 As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response Again, I think it's another fantastic question. And you see this in a lot of industries. Mainly in our one, I've been to many practices myself personally, a number of consultants, and again, I've seen a mix of people becoming design managers. I've seen a mixture coming from my personal manager. He came from the apprentice background and worked his way up. And there's other practitioners that have graduates building their ways up in that way to become design managers. Personally, I believe it's all just down to experience, to be honest. I think it's vital that design managers jump in at the deep end in a few different things to sort of – I don't know, possibly go to site a lot more. Not just be stuck in the office, so they have the appreciation of all different sides of the design management. Because at the moment unfortunately, you're stuck at financials and you never leave the office. And I think it can affect decision making and also checking designs. I think that's mainly the way to bridge a gap really is to get out there more as a manager.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I think that is a correct statement. I think it's becoming more logical that the contractors are now becoming sort of semi consultants. And what I mean by that is now BIM hascome into play, I would say the contractors are now being asked and basically forced to become sort of mini consultants. And I think that gap will be bridged in the next five to ten years down to that process alone. These guys aren't going to be just building walls and basically instructing people to pull cables in. They are sort of developing their design minds as well as being installing the buildings itself. I think that will bridge the gap. I think it is a correct statement and I think it's about working together really. I think it's still the construction team sort of being mini consultants and also for the consultant to basically when you're doing the designs, make sure one it actually works, but two, think of how it's going to be installed. I think that will bridge the gaps on both sides, to be honest, and I think that's a key thing.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response First of all, I think design is a very difficult process to manage, and I think everybody's different in how they design things. Unfortunately, there's not just one way of doing things. I think there's a number of ways you can design a building and you could have ten consultants design a building differently. So, I find it quite hard to manage people. I've done that personally on younger people. Whereas a design manager, I do believe it is a hard thing. And I don't think it's one that you can just sort of fix straight away, to be honest. I think every design manager is different. I think it's a hard question, to be honest. I think we'll move on, really

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I agree massively with this statement. As a young engineer coming up the ranks, I believe unfortunately managers do sort of get pushed by their clients to agree unrealistic timescales, and I believe that puts pressure on engineers to carry out the tasks as quick as possible and try and be as accurate as possible. And I think unfortunately that's where we fail as engineers. We get put under a lot of pressure from managers to succeed in everything we try to deliver for the client, but it does generally come down to what the client's asking the managers as well.

So, I would not say they are to blame as well. I think as a collective, unfortunately we are in a game where the fees aren't big enough. So, I think that is the biggest problem. But I can see with that stat of 80% of waste, unfortunately in bigger organisations, it's down to lazy management and the loss of communication between the top levels and to the levels at the bottom. I think that's the main problem, really.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining systematic management during construction. What is your experience?

Response My experience basically on that is the problems you can have when you go onto the construction phase from the tender stage. And basically, if you don't manage the phases correctly, this can cause a massive impact on site. Also, basically really down to programme issues really. If the correct phases are done properly from tender to construction. That is really my experience at the moment on that. Yeah, move on please.

Question Nr 10 Dissonance between designs in an multidisciplinary practise is often brushed under the carpet at design stage. How do you relate to this phenomena?

Response Again, I think that's another fantastic question. Unfortunately, we're in an industry where you've got mechanical, electrical, structural, architectural, BIM. There's a lot of sort of cogs in a big wheel, basically. And basically, I'm an electrical engineer, and unfortunately, we can have my colleague who's sitting next to me is mechanical, and we can still misinterpret things of who's doing what. And I think it's a key thing in our industry. How do we solve it? I think that's a bigger question in itself. But unfortunately, I think that happens in every practice, and it's something we as engineers need to resolve going forward.

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Ok, another fantastic question. As I said previously, I've worked in a number of practices, and the difference between having a manager with a lot of experience in building his way up the ranks and how to deal with people is absolutely imperative compared to someone who has come from a university background. The differences are huge. However, unfortunately, if you could mould a guy or a woman, sorry, who's come from an apprentice background and someone who's come from the university background. If you could mould them together, that would obviously make the ultimate design manager. I think it's a case of just building your skills as a manager from going to site more or being more academic if you're the other way inclined. But I think it is key as far as imperative. Sorry, move on. Sorry, I've lost that one.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practise is directly related to how managers can stimulate learning. A learning practise is an organisation skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate which gives you a sustainable professional advantage?

Response Well, working at another large organisation, they generally have a lot of online learning and targets you have to hit every year. Unfortunately, I'm not the best at doing them. I don't believe in them, to be honest. I believe that training should be set by your managers of how your career is going to be defined and what you want to do. I don't believe there should be specific goals for the full company that everyone has to hit. I believe everyone is individual and everyone has their own career paths that they choose. And unfortunately, bigger practices also want us to be productive as well. So, how they all fit into this little model, I still can't get my head around. But I do believe that you need to be more open of how you want your career to path out and map that out with your manager. But I think it needs to be more personal, basically, is my main objective of this question.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response Again, I think that's another fantastic question, and unfortunately, this does happen in building services. Ultimately, I think the BIM and the scenario that we're going into in the next five to ten years and probably further on will help be more collaborative with other industries. Again, working with an architectural model, an MNE model, and a structural model. I believe that will help the process. I still don't think it's going to be the total answer. I think unfortunately you deal with many different people where you've got architects who will like to sort of tinker with things, you've got engineers who'd like to be more sort of construction side, thinking about how it's going to be installed, and then you have structural teams who will sort of – it will impact of how walls are going to be constructed if we mount certain things as MNE consultants. Unfortunately, I think there's a lot of people who are very talented, a lot of people who are very skilled, and a lot of people who are very educated. And I think it is hard to be collaborative between them because everyone has an opinion. I think it's about basically communicating around the table, really. Getting together and meeting people every couple of weeks on a project to try and avoid any problems on site.

Question Nr 14 The increasing number of specialisms in the building services engineering design process, results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yeah, unfortunately, I think in my office alone I think people do work in silos. Generally, it comes down to personalities sometimes where people like to work with certain people and like to work with certain personnel. Unfortunately, what happens there is you get projects that are designed in the same way but are different sort of aspects. You can design an office in one way, you could design a library in a different way, you can design a sort of railway station in a different way again. Unfortunately, if you work with the same people over and over again in a silo, you design the same way for a different type of project, and that can become problematic. Unfortunately, as well, you have different types of people. You have the BIM , you have people who just want to hand mark drawings up, you have people who just want to CAD and things. This does impact the projects alone because you do start working in silos. I think that is a main challenge and I think it's going to be a major challenge in the next five to ten years with BIM coming into play.

Question Nr 15. Technical coordination, in the context of building services engineering, means working with and influencing other members of the design team so, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing cooperation, is a major aspect of engineering practise.

Response I think basically there you have quite a few key elements in technical coordination. And I think in my personal experience- Being electrical, it is a major aspect. Obviously, dealing with and working alongside mechanical engineers, there needs to be a key coordination aspect there. A lot of mechanical equipment does require a lot of electrical services to feed their equipment. And it's basically making sure we coordinate the best we can to make sure things aren't missed out in the tender specifications or the tender drawings where we've got our services being fed by electrical, who's providing the cabling for these outlets. Is it mechanical contractors, is it electrical contractors? But then also how we coordinate the aspects of the design with M and E to make sure it's coordinated properly in the BIM model itself. I think in my experience you have to be willing to sort of move things to meet the mechanical needs. Mechanically, you have to move things to meet the electrical needs. And basically, it's about working together to make sure your model is, one, coordinated, but two, that everything, M and E, works efficiently.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to coordinate all design activities, processes and resources in building services engineering practise. What is your interpretation of design coordination?

Response Design coordination… Basically, you've got levels of design coordination within BIM. You've also got sort of your own interpretations of that as well. So, I think it's about sort of agreeing a start point of what the client wants and what the client's needs are to then decide, one, what we are producing as the consultant, but also what the client is paying for. I think they're the two key elements to this because unfortunately we either become over-designing and not getting the fee for this, or we under-design and the client's not getting what they are basically after. I think that's a sort of key thing to understand before you go through the process of where we are in the coordination.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40% - 50% of the total work hours on a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Yeah, I think unfortunately we are in an industry where we are under pressure from the get-go. We are under pressure from the client. We are under pressure to try and win projects with a fee that probably doesn't match our expertise. And I agree with that statement, simply as I was saying to you, of the problems I encounter in the construction stage are from the design stage. However, there's a couple of key elements there. We generally don't receive enough information in the time allocated to us. Unfortunately, being M and E, we are the last ones in the model. Architects are constantly updating their models and updating their layouts, so I would say a lot of problems you do see in the construction stage are from the design stage, but generally that's not the full picture really. And I would say that's a key element really in all of my professional experience in the last 12 years. And I think the key element here is time. We are not getting enough time and we're not getting enough fee for our expertise. And unfortunately, the client is, and all clients are wanting the best product possible for the least amount of time and cost and I think that is the biggest problem in our industry.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomena.

Response This is very similar to question seventeen really. Unfortunately, we do not get all the information at design stage and we are paid as engineers to sort of assume certain things. These things can look really bad when they come to construction site. These can be a really good assumption as well. Unfortunately, when the time is up against us, we do make decisions and we have to sort of, one, either live by them, or rectify them on site. This can cause problems on site. It can cause cost implications. But unfortunately, without the full information at design stage, you are going to get these issues.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response I think that's a great question as well. I think with the industry is moving forward at a rapid rate. What I would say on that sort of thing is if it's not broke, just keep designing how you are. I think we are sort of getting to the point now where we're trying to put a lot of, for example, mechanical ventilation in buildings when we could just have a natural ventilation system. We are pushing LED and we are pushing it to sort of lighting control systems to try and save energy. Sometimes these are overdesigned. We've got to be careful that we're not going too far one way and forgetting what our – originally what our design sort of intent. What the client wants. I think that's the key thing really. It's what the client wants, what the fee is, and how we can best implement that in the certain building that we are providing.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response First and foremost, probably being biased, I think it generally works better because the building services generally are the last involved in the project as far as the layouts are finished and the building services get that last – it's sort of like the last minute chart reading in a project. The industry as a whole is generally run by the architects as far as a lot of projects I've worked on. Sometimes structural. But if a building services do run the project from start to finish, and say they bring more – how can I describe it? Sort of things like the major issues I've had on projects is like the voids aren't big enough. Ceiling voids, that is. We have a lot of problems in risers. Unfortunately, the architects make key decisions sometimes without involving building services when they are the leads. When the building services are the leads, we can advise them a lot earlier that problems could arise if this sort of isn't looked. I'd say really it can generally be a positive thing for building services to run it and it generally brings everyone together a lot better than, I would say, an architectural team, who are generally there – who tinker a lot more than, I would say, building services.

Question Nr 21 Performance management provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to step change in performance. How is performance measured in your practise?

Response I'd say performance is measured in a number of points really. First and foremost, it's how you perform in front of the client, how you perform in delivering a design that meets the clients needs, but also how you perform as a sort of communication background really. How you sort of present yourself, your punctuality. There's a few sort of different levels you can perform, your performance can be measured. Yeah, it generally goes on who your manager is really is how your performance would be measured properly.

Question Nr 22 Early engagement with the client and technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design deliverable output?

Response I believe that's a key element in a deliverable outcome really. Unfortunately, there's probably not enough consultation with the client from an early stage. And I also sort of voiced my concerns from the outset that an architectural conversation between them and the M and E doesn't happen enough as well. I think the design team as a whole needs to get together with the client at an early stage and sort of outline what the client's wanting and also what can be delivered. I think that basically the key. And unfortunately, a lot of the time communication doesn't correlate to the quality of the design because this process doesn't get delivered really from the outset and that's unfortunate. I think it needs to be better in the future.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design, so as to engage in a process of continuous learning?

Response I think that's a great question as well. Unfortunately, I think a lot of the time as a design engineer you are under a lot of pressure, and I believe everything you have made a decision on, rightly or wrongly, you are scrutinised. And I believe that sort of reflects in how your design is done. Unfortunately, we bump a lot of the design up to sort of defend ourselves all the time, and I would say that's – I think that's a key thing that you need to learn as you sort of go through your development. Unfortunately, we are defending ourselves a lot of the time in this industry and I think you learn that sort of from a young engineer age all the way up and unfortunately, you have to continue to do that all the way until you become management, until you retire basically. But I do believe this happens a lot and it's unfortunate, but discrepancies are found a lot in our design and it's how we defend them really.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe continue as a successful working environment.

Response It's a great question as well. I've worked in a number of different practices as I've mentioned previous and I believe the strongest thing you have is basically teamwork. When a project is going well, everything is great. When a project is going – I wouldn't necessarily say wrong, but when you're under pressure, it's how the team as a whole gets together and see how we can deliver together to help get the job done. I think that's the best quality we can have in a team. And I think that is the most sort of thing you can contribute to a successful working environment really is how your team is gelling together. And without that, we will deliver nothing.

Question Nr 25 The use of design decision making tools, in the propensity of power distribution, general and emergency lighting, lifts, lightening protection, heating, ventilation and daylight simulations, wind and solar energy, etcetera, may be useful for guidance. In your professional experience how accurate are decision-making tools in your specialism?

Response Generally, they are key. For example, lighting, we use many different packages, sort of dialogues, and we use Realux. For example, power distribution, we use Amtech. These generally are used as a guide, but they are a good guide. We generally do design off them. I would say generally in my 12 years of experience, we used them from day one and we will continue to use them. But unfortunately, we aren't an expert in everything. We do have to use a lot of specialists like lightning protection companies, like daylight simulation. People who can help achieve what we want to achieve in the design. And I think we shouldn't be afraid to use other people's software and get extra specialist help when required.

Question Nr 26 Building Information Modelling (BIM) is not just a fancy 3D model, it is about moving away from the traditional industry practises of producing multiple and independent paper based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response I think that's a fantastic question again. I think it's going to be a sort of big challenge for the industry in the next sort of five to ten years and maybe going onwards. I think it's a big transition for a lot of different people. I'm from the younger generation. I've came straight into doing CAD, straight into doing BIM as a whole. But I think unfortunately you've got a lot of management who have never been involved in anything such as BIM and they are getting used to it and these are the people who are bidding for work. These are the people who are putting financial packages together for the client. And they don't really have the understanding that is needed to price a job and also the understanding of what is going into a model. I think it's going to take a lot of time to develop that for all within the industry to be honest, but I think it's a great move by the industry and I think it will only benefit everybody from the client, from the contractors, and also the consultants. And it's just about working together to make sure we achieve everything together as one to make sure the client is getting what he's paying for, basically.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time, with more user friendly, flexible, intelligent and parametrical user environment. How has your experience been thus far?

Response Unfortunately, I've never been privy to using Magic CAD, so I can't really comment on that question.

Question Nr 28 Final question. Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design coordination between disciplines leading to install-ability issues.***
- ***Poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign.***

As a direct consequence of these deficiencies the impact in design consultancy practises is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response Well, fortunately, I've worked with my design management for a number of years now and we've gone from two different consultants, both Atkins, and now we both work at [00:08:31]. And what we've managed to set up is a process where we review our projects, good projects and bad projects. And what I mean, it doesn't mean that something's gone drastically wrong, it's just how we may have overspent or decisions that couldn't be made at the design stage. But what the best thing is to do is to go through a review and the good points and the bad points of a project and how we can learn from them as a team. And I don't think it's just a team as in one office. I mean as a company and basically as an industry really. We don't talk about – when we do things good, we don't celebrate we done things good. And when we have done things that haven't been so good, we don't investigate them properly and how we can avoid in doing them in the future. And I think that's the key really. We need to celebrate when we've done good and pat ourselves on the back a bit more, but we also need to investigate more in how we can do better in the future because at the end of the day, it will go around in circles and errors can be – we are human at the end of the day. And it's about sort of everyone getting together and how we're going to succeed together as a team and as a company for the future really, to basically get in everything we can for the clients. But also, to be – we are at the end of the day engineers. We are managers. We want to do well in our careers. And it's about everyone joining together really. So, our organisation at we do a lot of review work. But I think as an industry, we need to look at that more and how we avoid the dysfunction as a whole in the practice really.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Project Electrical Engineer,, Raymond Reilly (Researcher)*
Date/Time	*20th December 2018, 10.00am*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*7 (Project Electrical Engineer)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Lengthy! I suppose really it starts when you are talking to the client originally, that is where you begin and you try and get their expectations out and get it onto paper, get them to sign it off. And then you kind of continue conversations with them and go back and forth between the rest of the design team and flesh it all out. After that then you take it to construction and there is an element then of design development after that as the building gradually goes up. It is almost an ever-ending process until the building is closed and done and sealed.

Question Nr 2 Ineffective design management results in extended design time scales and the production of poor quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response I suppose, in my experience, a lot of problems that arise, there is really no way to know that they are coming up until you are actually on site and all of a sudden you realise that a light switch can't go here for whatever reason or there is duct passing right through where you want to bring your cable trays, so you have to develop these things on site. That is where the design development really comes in.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly educated and specialist trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practise? Can you identify potential improvements in academia to produce better prepared graduates?

Response Absolutely. I did electrical engineering and I suppose, what I learned in college, a lot of it really doesn't relate to what I do day-to-day. Now, I suppose I started as an electrician so, I had a leg up and I saw that that with our graduates coming in here. When they come out of college, they are extremely raw and green, and they don't know what they are doing, even at a technical side of things. You have to kind of help them and bring them along. The other side of it is that they come out of college and they have no idea what to do at a meeting or in front of a client. There is a huge learning curve there that they have to try and overcome at some point. That is where I would say they are falling down. They don't bring them to site enough. They don't know the realities of putting in a building and all the hundreds of personalities you may have to deal with.

Question Nr 4 Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your professionalism.

Response I would agree. This industry is kind of so small, it is all about personalities. Inevitably you are going to end up working with the same people again and again and you have to be able to get on with them. The technical issues tend to be relatively small and they can all be solved but, you really need to be able to work with people day to day.

Question Nr 5 As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. How do you foresee bridging this gap?

Response I suppose I am kind of stepping up towards a design manager - that I am the day to day man on the ground. Yeah, it is something that I am not sure if it can actually be taught. It is something that you just have to learn yourself. You have to figure out your own way of doing things because everyone is going to do something different. Now, you can put in structures to keep a track of things, keep a track of changes. But in the end, you have to figure out the system that works best for yourself.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I would agree. Contractors are extremely black and white. It is either right or wrong, it is very hard to push them to find a way around to help you out. So, where you are very much solution focused, they are, if it is on the drawings, that is it, whether it is right or wrong.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah. It can be a managerial problem in that the information gets lost in translation somewhere. You are under massive time pressure to get something out or there are too many projects going on all at once. So, things start to get lost then. That is where the fault comes because if you have all the time in the world to do everything, then there are no problems because you can take your time and make sure you go through everything but the other side of it is that there is always a tender, there is always a date you are working to and you have to hit that date. So, you have to have an element of time pressure**.**

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I wouldn’t say that there is a huge amount of waste really. I suppose you just need to be clear on what you are asking someone to do. That is the main thing. Engineers now are taking on more roles, taking over especially more kind of specific roles and I think that is actually better, to be honest I think it is more efficient. By the time I mark it up, especially if it is a small thing I need changed, by the time I mark it up and give it to the CAD team, I would have it done myself twice.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining systematic management during construction. What is your experience?

Response Again, I suppose this always goes back to that there is always going to be an element of design development and I think, as long as you factor that in, you are going to have that time there, at some point, during the construction process. Then, I think it shouldn’t cause masses of issues. Then again, I am only stepping up to that end now.

Question Nr 10 Dissonance between designs in an multidisciplinary practise is often brushed under the carpet at design stage. How do you relate to this phenomena?

Response Yes. This is a big problem, even in our office. We are all working in silos, all the time and it is because we are trying to get something out the door. And you end up not telling someone else. For instance, there was heat pumps went into one of our projects. I only knew about it when I was asked by the contractor to provide supplies. I never knew it existed before then.

Question Nr 11 Successful building service engineering design management needs management, excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response I suppose, you need to be showing people the way forward. You need to be clear on what is going on, where we are heading, and you also need to be available to answer questions for people when they come up. That seems to be the way it is working in our place and it works quite well.

Question Nr 12 Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practise is directly related to how managers can stimulate learning. A learning practise is an organisation skilled at creating, acquiring and interpreting, transferring and retaining knowledge. How does your practice learn at a rate which gives you a sustainable professional advantage?

Response I suppose the way I have always learned is on the job. I mean, there no better way of learning how to do something when you have to get it out the door and you need to drive yourself on that. There are different things you can read online and you can do in your own time that are definitely well worth it but, there is nothing beats sitting down and actually trying something.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practise. What is your experience during the project life cycle?

Response I would agree. Again, it comes back to those silos. Say, architects might add in a door here in a building and they don’t tell you that that door needs to be access controlled. And all of a sudden you get to the site and you have a contractor sitting looking at you going 'Do you want access control on that door or not? It is not in your drawings. You need to pick that up'. So, that is kind of where it all comes back to... That is where things fall apart in the design process, it is not talking to each other.

Question Nr 14 The increasing number of specialisms in the building services engineering design process, results in technical staff tendencies to work in silos, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Again, kind of the same thing. We have experienced that, and I think we will continue to experience that. But that is just the nature of the business. It does cause problems. The only way is to communicate. Maybe there needs to be a central person that everyone feeds into and they send out the information out to all the relevant parties. Maybe that is the way forward with it.

Question Nr 15. Technical coordination, in the context of building services engineering, means working with and influencing other members of the design team so, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how coordinating technical work of other people, by gaining their willing cooperation, is a major aspect of engineering practise.

Response Yeah, you do. You need to build a working relationship with people. It starts, I suppose, by just being polite and again, you get up, and you sit down, and you talk to someone at their desk 'Right, I need to get this in. How does that affect you?' or 'I am putting in a fan here, what size cable do I need, what is the load on that fan'. Again, it is getting out of your silo and talking to everyone.

Question Nr 16 Design coordination is a purposeful and goal orientated activity which aims to coordinate all design activities, processes and resources in building services engineering practise. What is your interpretation of design coordination?

Response I suppose it is that everyone is singing off the same hymn sheet. You need to be feeding information back and forth between all the members of the design team. And I suppose, it starts maybe with the architect giving what they want, what they envisage for the building. Then, we look at it and we go from an electrical perspective, what you are asking, can’t be done. We need somewhere to mount a light or there is going to be a break glass unit will have to go here. You will need to remove that glass section. That is where it kind of starts.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40% - 50% of the total work hours on a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response I would say that that is absolutely correct. I would say you are working another 50% on top. It is much harder to clean up a mess than to make it. So, if you get it right the first time around, then you avoid all the problems down the road.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. Describe your experience of this phenomena.

Response Tight deadlines are always a problem and will always be a problem. The balance there is to manage client expectations. There is no point in telling them that we will have fifty drawings out in the morning when we can't do it. When you are trying to get things out too fast, you only end up making mistakes, that is what the issue is and, that knocks on down the road then. Then, it becomes a much bigger problem than saying, 'Look, it will two or three days before we get this out'.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Have you adopted a non-reinventing the wheel approach to your design?

Response Yeah, I suppose, when I started as a graduate I was reading and printing absolutely everything I could get my hands on and I still have a lot of the actual hard copies printed off in my locker. At this stage now, because I have gone through the role so many times, I don't need to refer to it as much any more. But, you do have to be careful when new standards come out, you need to print them off and familiarise yourself with them. It doesn't happen all too often, but it is something you can get caught on. So, it is important to kind of keep this up to date.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response I actually really haven't been involved in a project where we were leading the programme.

Question Nr 21 Performance management provides a means of distinguishing between perception and fact at three levels - individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to step change in performance. How is performance measured in your practise?

Response I suppose we have a very strict one to nine box system and you fit in somewhere into that matrix. The realities of it is that, well, you are meant to set goals and achieve these goals throughout the year. That can sometimes be difficult. You might maybe try and take too big a step on them or it just gets too busy to be doing the extra work to achieve these kind of goals. These personal ones especially. Likewise, your line manager then is going to be what makes the difference there, because he or she is going to know what you are at day to day and where you are. They kind of feed back to you and tell you actually how you are performing, and it seems to be working well. I would say, sometimes though, that we are in a very big company and the individual can be lost inside in that company and it would be very easy to fall through the cracks.

Question Nr 22 Early engagement with the client and technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design deliverable output?

Response Absolutely. Without a shadow of a doubt, the client needs to be there and very clear on what from the get-go, because otherwise you end up going down tracks of doing a pile of work that they don't want in the end. The client needs to be clear on what they want from the beginning. If they are not, you are only doing a lot of aborted work.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is, to reflect on your design, so as to engage in a process of continuous learning?

Response Absolutely. I mean as you go on, you always learn something new. You figure out how to do something better or more efficiently. You learn by making mistakes. So, if you can't accept your mistakes and reflect on them and learn from them, then you are not going to end up being a good engineer.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe continue as a successful working environment.

Response I suppose, I know it sounds small but, there has always been chat in the office and I find that makes the day a lot easier. There is always a bit of a laugh and a bit of a giggle about something, at some point. When you have that, it makes the day shorter. I would hate to sit in a silent office where no one is chit-chatting or anything like that. You still manage to get your work done but it breaks up the day. You are not just zoned staring at a screen all day and just going through the motions.

Question Nr 25 The use of design decision making tools, in the propensity of power distribution, general and emergency lighting, lifts, lightening protection, heating, ventilation and daylight simulations, wind and solar energy, etcetera, may be useful for guidance. In your professional experience how accurate are decision-making tools in your specialism?

Response I find, especially in lighting and lifts, they are extremely accurate and they are vital, for the simple reason that if you were going on maybe a gut feeling just looking at the size of a room, you might actually end up putting in too many lights and you might over light it and in the end, it costs money. It is about efficiency. That is where these tools come in. It is more so reducing quantities in the uplift in that rather than getting the minimum out of it.

Question Nr 26 Building Information Modelling (BIM) is not just a fancy 3D model, it is about moving away from the traditional industry practises of producing multiple and independent paper based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response I suppose, I didn't really have too much of a challenge in that I started off with both 2D and 3D. So, to me, they are kind of one and the same. I prefer working with 3D. I think it is an easier tool to use. It is more user friendly and you get a more accurate model. You can put in heights. You can put it exactly where you want it in the room. The only thing I would say is that we possible don't use it to its full effect.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time, with more user friendly, flexible, intelligent and parametrical user environment. How has your experience been thus far?

Response I agree with that statement. It is definitely more user friendly. You can put in every single model you can imagine for every single piece of equipment. You have all the parameters in there and you can put that anywhere in the building and you can do it quickly. What we really should be looking towards doing is putting in all our distribution boards with the circuits and then can pull our schedules out of it.

Question Nr 28 Final question. Inefficiencies in engineering practise at design stage are noted as follows:

- ***Lack of design coordination between disciplines leading to install-ability issues.***
- ***Poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality.***

As the design process is found to be a major source of problems at construction stage even to the extent of undermining systematic management, the following deficiencies are identified.

- ***Inferior quality of installation,***
- ***Time delay of installation,***
- ***Increased cost of installation and redesign.***

As a direct consequence of these deficiencies the impact in design consultancy practises is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with practise dysfunction?

Response I suppose, in my experience, we have been relatively lucky. We haven't had too many major re-design issues that we had to do. So, we haven't really hit the absolute low point on that yet. But I suppose, you just have to make the time to correct the design. That is what happens in practice. It does work, and you do get it out the door. Maybe it is a case that you have to do extra hours to get it out the door and get it right. That is the way it works

That concludes our interview. **END.**

Appendix 14 *Case study interview participant transcripts (Internal – PCC consultants)*

Reference	*Engineering Management*
Attendees	*Managing Director – Programme & Cost Control, Raymond Reilly (Researcher)*
Date/Time	*25March2019, 1.00pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	8 (PCC Practice Lead)

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) ***the design and construction stage in the context of people, processes and technology, and***

ii) ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Well I don't know really. The, so I suppose from a QS perspective one of the big differences is the level of design. So say you're looking at an external wall with a window in it, the Designers will pretty much design everything. They'll describe the type of blocks that are required, the type of mortar, the type of joint in the mortar, the insulation, the fixings for the insulation. Like so every bit of it gets designed by a Designer, certainly under the traditional approach. Whereas building services engineering is more - there is a lot higher degree of design that sits with the Manufacturer and Supplier. So I think that's probably the principle aspect of it that QSs would focus on really, is that it's really, the design is taken to a less complete state typically, because it's, because there's a degree of it that goes through the Manufacturer and the Designer.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Yes. So, yeah, so ineffective design management, design timescales and production of poor quality tender documentation. So, yes, absolutely that applies to building services engineering. It also applies to any other type, any other elements of design really. So any design issues have to be resolved at some point in order to build. And how your professional experience relates to this trend. So yeah, that is the case and I think we do find that design sometimes isn't as complete as it should be at tender stage and those unresolved issues have to be resolved at some point. So I think what, there's extended design timescales, but there's also potentially extended construction timescales and increased costs. So from a QS perspective, probably the ineffective design management resulting in poor quality tender documents results in kind of cost and results in cost and delay, would be the bit that we particularly focus on I would have thought.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response So am I here kind of speaking as an observer of engineering and people coming through engineering colleges and graduating and so on? Yeah, so the design, I don't know, historically with Designers that have come from a craftsman background, I suppose they probably would have, that they would have gone through, 10 or 15 years ago you'd probably have more. Designers who had gone through the trades and gone through BTEC and that sort of stuff, rather that straight into a level eight degree.So there are, yeah, so it is definitely more academic now. So people come out without the practical experience, so and what that means, it's probably reversed the way around that it used to be. You used to get your practical experience, then you got your academic qualifications and they made more sense to you, because you had had a practical background. Now it's the other way around, that you go straight from school, you study stuff and you probably only get to the point of having a proper understanding of it some time after you graduate, when you've seen, experience the realities and the practicalities of it. So, I don't know, do they do, do they do year out for graduates?

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Yeah. So I think personality, communication and negotiation are really important, but in our business they have to, you have to have a fundamental design or you're in trouble. So if you have all of that, but you have no technical knowledge, then it's going to cost money anyway. So we're talking about financial success, if you're talking about the financial success of a project, if you do your tender documents, the Contractor is going to hit you for the costs, no matter how good you are at communicating and negotiating. Now you may find a better solution quicker through your personality and you may find a better solution quicker and cheaper through your personality and your communications, but fundamentally if it's not right technically, it's going to cost money.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response Yeah, don't know really. That's kind of beyond, I wouldn't really get that far into building services engineering to really see that, but I think the same thing applies to everybody. This move from being a technical, great technical projects person, who has all the technical solutions, to then being a Manager of people and the output of other people, is a gap that we don't, we just assume that people will move from one stage to the next, but I think we need to be more focused on understanding that that is the progression and being conscious that we should be mentoring and training people on their journey from one to the next.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response Oh my God. So let me go back to the start of this. So, engineering has been [00:08:58.2] a technical and social process…. What do you mean by social process? Do you mean in terms of the social as in terms of environmental and climate control, that sort of stuff? Or social as in collaborative working or….? Oh right, okay, yeah. So, yeah, so that probably is the case to some degree, that you have people come up with technical solutions, which they, which work in concept, but then somebody has to build them on site, but I would say there is this kind of trend in building services that building services Consultants do work very closely with their Contractors. So certainly for an external perception, my view would be that more often than not the Building Engineers and the building services Contractors go away into a huddle and work out what the best sort of practical solution is and then it happens and nobody ever, nobody actually gets in detail of it and maybe that's right, but I get the impression that building services Engineers and Building Contractors are actually pretty collaborative, maybe more so than quantity surveyors.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yes, so I think there is a degree, there obviously is a degree of complexity that comes from the technical side, but I think the complexity is sometimes made more challenging because of the way that it's done and obviously how your, it's not really clear how work gets divvied up in a building engineering team, but that must have an impact on it. But also the stakeholder engagement and level of change typically has an impact on the complexity. So more often than not there is a level of change during the design, which adds to the complexity and if you call that managerial complexity, then definitely there is. So, obviously it would be easier if you had a really clear brief and a brilliant Manager who divided up the work in the most appropriate way and you ended up with your simple solution, but it doesn't tend to pan out that way.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Yeah, well I don't know whether it's 80%, but I would wholeheartedly agree that there must be a lot of waste in every busy construction consultancy office where people are working under direction, the people giving them the directions and managing them don't explain in a clear way as they might and don't maybe check in as often and don't review stuff as often, so you end up with people going off and doing work and then having to re-do it or it not being what people expected**.**

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response I think it depends from project to project. So I would say in some instances the building services engineering is found to be a major source of problems to subsequent phases. Even to the extent of undermining systematic management during construction? Yes, because it's an individual element that can disrupt everything, but being honest, it doesn't happen to that degree very often.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Then covering up for other people's cock-ups, is that what you mean? Yes. So, yes and no. It probably does happen, but I think it happens in… in Ireland it happens in normal design teams that work together anyway. So if you were to look at some of the projects that we could have kind of worked on in the past where say you've got a consistent team working the whole time, that team do have each other's backs and I don't know whether they 'brush under the carpet', but help to find a resolution before it becomes a problem. It does happen for sure.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Hmm. Yeah, well I think all management is about people really. It's about leading people, so I don't know whether that's any different in a building services engineering practice than anywhere else, but I suppose the only difference is that building services is quite a specialist, technical place. So, lead people, you need to understand where they're coming from, from a technical perspective, so you do need that technical knowledge.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response So I think in theory recruiting the best, so that you have people coming into the business who have that, who have good levels of knowledge. Then being an organisation of a scale where it can invest in being at the cutting edge and being in an organisation where inevitably some parts of the business are ahead of others and where that information can be cascaded around the place, through the disciplines and so on. I think they are, I think they're the key things.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response Yeah, I think that it's the case that there is, that for it to be truly beneficial you need to have the team following through and the team learning from the lesson. So if there is an inefficiency at design stage, that the people who generate that inefficiency are aware that it generated a deficiency at construction stage and therefore they're alert to it 'til the next time

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response. Yeah, so no question that there is increasing specialisms. So the number of specialists and it's due to kind of legislation and all that sort of stuff and planning. So, yes, it's certainly happening and yes our team has experience of it. I think it's all about how you integrate those specialists into a team, because you're going to find that you're not going to have, in your multi…. In a future multidisciplinary design team you're not going to have all those specialists sitting with you all day, every day, because you're going to need to call them in for other businesses or other parts of the business. So it's all just about how you integrate them into a part of the business.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response Yeah, well in terms of, my observation is that… my observation. Yeah, so my observation is that it is a challenge, because the inter-relationship of all the different elements of the building services and fabric is vital, so if you don't have a collaborative team, somebody goes off and does their bit without collaborating, then it is a major challenge. So you do need to have that collaborative team and obviously technology is hopefully moving us in that direction.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response Well in the simplest terms I would interpret it as all the different elements of the design being co-ordinated so they work together from an aesthetic perspective, a technical cost and everything.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response So 75% of problems encountered at construction stage are generated at design stage? Yeah, I think that's probably true. 40 to 50% of total work hours of a project may be required to rectify such deficiencies? That sounds like an awful lot. It could be true, but it sounds like an awful lot. But it definitely happens.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Yes, I have recent experience of design processes being squeezed and it generating all sorts of problems.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response I don't know. My observation is that everybody needs to do that. Not sure how set up we are for that, in the sense do we have all the platforms? Do we have all the standard libraries of documents and solutions? Don't know.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response So what would I have worked on that building services led and managed the program? I'm trying to think what projects we'd work on that… yeah, we probably have worked on a couple where upgrades and things like that. Now the one in Dublin was Project Manager led, but there was some in Galway. So I haven't worked on many projects which have been Engineer, building and services Engineer led, is the honest answer, but my view is that with all, whoever leads, there are some people in every discipline who are good at project managing.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response The performance measurement provides a means of distinguishing between perception and fact at three levels; individual, project and organisational. Okay. So performance measurement at individual level is carried out through the performance management and reward process. So a very structured process where people set goals at the beginning of the year, review them during the year and reviews are at the end of the year, to the point that they actually get a rating at the end of the year. From a project level, in terms of performance there are lots of financial matrices associated on the project performance. There is the net score, so the project financial performance. There is a net promoter score, which measures whether a client is likely to reappoint you for the next job. Are they a promoter? And I suppose from in terms of the quality of the output, it's more to do with ISO and that sort of stuff and part of our review processes that we have, reviews and tier one reviews and that sort of stuff, which do flag any technical issues, but as project and organisational, so yeah, so the organisational measures are primarily financial. Yeah. So there are others, like awards and sort of stuff.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Being really clear about what they want certainly improves the quality of the design. It's not going to change their minds, but along that journey.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Hmm. I don't really design, so I'm skipping that question, Ray**.**

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response So my team's unique qualities? So I think everybody in, typically everybody in our team has a principle focus of wanting to come in, do a good job and deliver a professional service and they'll walk away where their client is happy with the project and they as individuals are happy with the project and I think that is everything. When you broaden that I think in general people feel their teams that they work within and the people that they work around to be very supportive. So I think people do believe that they, the team around them and their workmates contribute to that successful working environment. Hopefully just the employment position of the people that do have full-time, permanent, pensionable and good benefits, all that sort of stuff, it takes away some of the stress, so hopefully adds to that successful working environment and then use of technology and hopefully using good technology and having access to good technology. To move things forward from a technological point of view, I think people are happy with that, but yeah, those sorts of things.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response Now, Ray, I'm going to skip 25.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response Okay. So I don't do any designs, so my observation is that in the Irish construction industry everything is so LEAN that it's hard to, wherever any investment is required, like computers, like time training, like software, it's hard to get the industry to invest and our clients don't recognise the value of building information modelling and our clients don't recognise the value of or the importance of kind of research. So it has a knock on effect of there not being massive incentives to do it. It is easier for us where we're working all in the same design team, on the same system, but I think design on multidisciplinary projects is quite significant.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response Now, John, I'm not going to ask you 27.

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response All of the jobs in AECOM just run perfectly well, I'm sorry. Yeah, so we have and how have we dealt with them? I think we've dealt with them through kind of detailed project reviews. Where it's happened on a live project in construction, detailed project reviews, it's bringing in external team members from within the organisation to do peer reviews and that sort of stuff and we've, I think in dealing to prevent repeat performance and repeat failures we've introduced the kind of the 'Healthy Start' program and I would hope that our kind of quality management mechanisms would pick it up as well, sign off on all the rest of it, but it could always be better.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Regional Director – Programme & Cost Control), Raymond Reilly (Researcher)*
Date/Time	*28March2019, 4.00pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	9 *(Lead Cost Consultant)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response The design process. I'd say for us it's much the same, to a certain extent, as traditional design process with the architects, obviously timings in relation to coordination between architecture and the MEP building services engineering to make sure everything is coordinated. Normally the architecture might happen ahead of MEP but other than that the processes is much the same from any project that I can think of. Is there any one that would be different? Nothing springs to mind, but yeah.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response I suppose it depends on types of project, whether private sector or public sector. Although possibly not enough. What you'll often find is with public sector contracts the design should be, in order to be in tandem with the capital framework guidelines it should be fully comprehensive for tender stage. So that should have the relevant design timescales required in order to have good quality tender documentation for public sector work. I won't say it happens all the time, I think what goes against it is guns are put to people's heads to maintain programmes rather than to get comprehensive design and that leads to unresolved design team issues. I think the issue that arises in the private sector that doesn't arise in the public sector is people will go out still now with PC sums, provisional sums, all that coordination ends up getting tied at post-contract stage and leads to a lot of unresolved design team issues. And that tends to be the main difference that we would see between private and public sector in relation to those two processes and how they work tendering wise.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response Take the first part – has Irish education system adequately prepared you for practice? I would say… I won't go as far as to say no, but I would say probably not. I think although engineering or quantity surveying or even architecture or the majority of the service lines, regardless of what they are, education… you can only be educated so much. Nothing can take place of hands on experience in anything.

And unfortunately it falls into a bit of a trade in that respect. So therefore improvements, I think, is the more practical side of providing that, for want of a better phrase, trade experience for graduates prior to graduation as opposed to after graduation, I think would be beneficial.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Interesting, I never heard that before. So it's an interesting stat. Could I see it's true? Yeah, it probably is. Or I could see how it could be probably true. I'll take it as face value. I think communications and negotiations are key and I think… how I notice the difference nowadays, I think with technology people are using email, etcetera, a lot. So I think some people with more experience who are willing to pick up the phone probably get stuff resolved a bit quicker and a bit easier. If people are willing to talk to people eye to eye and eyeball them they're probably going to get stuff resolved a bit quicker. So it'll be interesting to see how that works out over time with people. But I'd certainly say, explain how the statement applies to your engineering team, yeah, I'd say that a lot of our job, I'd say, yeah 80% of our job comes down to communications and negotiations as opposed to technical lead. So the technical side of it is important but if you can't communicate what you're trying to get over the line, you can't negotiate it and get the price agreed, and if you can't lead it and manage it well then it's not going to work.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response Practitioner to management. How do you foresee bridging the gap? Once again the only thing that comes to mind is once again hands on experience. I think if you're involved in enough projects and enough design team meetings you'll see what other people are doing there. You'll learn from the project, you'll learn from what other people are doing. You'll see whether you have the skillset to do what other people are doing. And then you can push to possibly go into that more management style role once you start getting involved in projects. I think that will come from hands on experience.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I can understand the statement, I suppose. Some people are trying to be conceptualised. They can see the concept and what the end result should be and how they get to that, the road that needs to be travelled to get from A to B is less of their concern. While for contractors, how they travel that road and how that road is done and how quick it takes to travel down that road, and what type of road it is, is very important to them in order for it to work from a practicality and obviously from a financial point of view. So I could understand why people would say that, yeah.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah, probably there's an element of truth in that. I'd still say there's some element of technical requirement, especially in order to have a fully comprehensive and coordinated design, I think, does take a level of technical requirement. How much that is you can argue but obviously then managing that process to make sure that everything is technically coordinated in order to minimise issues at construction stage, obviously the best and most comprehensive and coordinated design that you can have at tender stage will minimise that. And it'll always minimise it. So it's a bit of both, in my mind.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Oh, do I agree with this statement? Not too sure, is the honest answer. Could it be true in certain instances? Yes. How I'd possibly word it is I would say that there's a large amount of wastage in how tasks are set out and managed in relation to clients' requests. And then those then changing again and people having to redo things once, twice, three times. So it's actually the management of the client as opposed to management of ourselves. But once again that's easier said than done depending on the client.

So how do we envisage such communication problems may be improved? I suppose where humanly possible clear communication with the client on deliverables. And then down to the team. And that should cascade down to the team. So once the deliverables are clear, then hopefully the amount of wasted time shouldn't happen too much.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response Building services engineer, as opposed to architecture or…? Building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent. Yeah, can be. Yeah. Building services engineering is found to be… Yeah. It can be. I think where it can be really problematic is on the likes of refurbishments and all that. But once again what we've found is trying to get clients to where they'll allow adequate fingerprinting to occur in advance is sometimes easier said than done. I think people's trust in 'as builts' can sometimes be sorely misplaced and push for nothing more than that. Sometimes people are scared to do, especially in those types of projects. So that definitely leads to subsequent issues going forward. On greenfield sites, the design process on MEP, possibly. It possibly has more knock on on other effects. So if there's something wrong with MEP then it impacts the builder's working connection, which impacts then the architectural and/or other trades. So yeah, the knock on can be sometimes a bit more than just services only, which is, yeah, a problem.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response God, I wouldn't notice it more, I mean we've worked in multidis and we've worked as a, I suppose, a sole trader back in the days when we were PM and QS. I personally wouldn't find that now that we're part of a multidis that things are brushed under the carpet. If anything I'd say that you've got a relationship and you possibly might pick up the phone to someone a bit quicker rather than hide behind the inadequacies of someone who's got a separate contract and you can sit back and blame them at a later date. Whereby in a multidis, I'd say it's the opposite, you'd probably pick up the phone because you know you're going to be tarred with the same brush and you want to actually get the issue resolved, rather than it's moved down the line.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Management is, I suppose, what you want is people with one, good technical skills, and people with the knowledge, and once again going back to that word, trade experience, who've got the experience of projects, who have seen issues, who can see issues coming around the corner before they occur, and help mitigate against them. Especially in relation to clients' wants and needs. So the client can be steered in the correct and right way forward in relation to a project. So, as it says, interpersonal are imperative, yeah. Good communications is… yeah, it's probably the most important thing to get those points across.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response Well I suppose for us I'd like to think that we actually have quite formal training processes in Aecom. More so, I think, than any other I've ever seen. And I would undoubtedly say more so than any of… knowing people working for other practices, so definitely more so than I'd say any of our competitors. I'm not too sure what ARUPs do but certainly from a PMQS point of view I would be very surprised that any practice does as much formal training as we do.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response I can understand where that's coming from. Would I say it's typically in serial non-collaborative? I think that's not necessarily true. I think it has to be somewhat collaborative, otherwise you'd never get a set of tender documents out. There has to be some level of coordination there.

If it was non-collaborative there'd be absolutely no coordination and every job would fall at the first hurdle, which doesn't happen that often, thanks be to God. So inefficiencies at design stage leads to deficiencies at construction stage, yeah, that's obviously true. And once again it goes back to the goal on all projects where humanly possible, is if you can get comprehensive design, well-coordinated, up to tender design change, the likelihood of deficiencies at construction stage and dysfunction will be mitigated. And I think what normally happens is… it's no necessarily the design process, I would normally say what really kills the design process is the pressure on programme, which ends up shortening that design process, not allowing people to be as collaborative as they need to be.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yeah, I've seen it… not necessarily in house specialisms but more out house specialisms. So where you'd start seeing issues such as items that cannot be designed in house and have to be performance spec. So you end up with a lot of performance spec works, say underfloor heating, BMS, a few others. And there seems to be more and more items going in way performance specs. So that can be an issue then post contract with coordination when there's a lot of performance spec items. So I do see that as a challenge going forward.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response Yeah, so I've touched on it before. Like coordination of all technical work is key to a successful project because you have to get all service lines and designs singing in harmony, otherwise the technical documents won't work when it comes to the contractor having to build a project. So obviously having that willing cooperation obviously is very important. I think that's why I think if you look at most projects and design teams they tend to be teams that have worked previously in the past together and have those sort of relationships. So that they're able to articulate to each other appropriately, they're used to communicating to each other and they're used to cooperating with each other in order to come up with a properly coordinated design.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response I sort of alluded to it in the last one but, yeah, design and coordination is, as I said, the architect, if things are done comprehensively enough that all things can be coordinated, from the architectural design to mechanical design, to the electrical, protection services, if required, or any other specialisms, and then along with the structural design or the civil design, so that at the end of the day all documents are singing in harmony with each other to the final end product of the building or whatever it may be, road, bridge, that needs to be completed.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response That's fair. Yeah. You'd sort of agree with that and it goes back to this whole thing of the issue being that you're going out to tender with a non-complete design. And it's just at what stage is that non-complete, obviously it can be a greater issue in the private sector where you could have a large amount of PC and provisional sums. You've gone out to tender, someone's expecting that to be the end price, yet I remember going back to the early nineties where you'd a job and I think… we went out to tender and we worked out that something like 70% of the project still had to be tendered on PC sums and provisional sums. So you could work out the level of coordination that still had to be done. But because of programme everyone was willing to proceed on that basis to get things up and running. So that can be a nightmare. We don't have that in the public sector at the moment to the same extent because you're supposed to have a full comprehensive design now for the GCCC projects. So it should be less of an issue. We have had issues where we've had to, at tender stage, state that we believe the documents aren't up to scratch and we have had clients who've written it… public sector clients, written it into our contract saying it's the quantity surveyor's responsibility to comment on the adequacy of the tender information at design stage. Which also puts an onus on ourselves to make sure that the deficiencies for construction stage are mitigated where possible.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Yeah, they can't be… shortening any period generally will never work. The only way you'd say it's worked is sometimes in some design processes they've got an element of programme there for value engineering. And if you're willing to skip that process and buy into it is what it is and we're going to live with it regardless of how much it'll cost us, then so be it. And you've got a client who's willing to push on programme wise rather than… and they're willing to put costs lower down the list of priorities, then it is possible to squeeze certain things. But there is always going to be an impact if you squeeze.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response For us, don't do much design as quantity surveyors, to be honest. Have we adopted not reinventing the wheel? Yeah, I think to a certain extent we haven't. Now obviously information in the years gone by has now gone from paper format to electronic format. So I think we all had to change that. I don't think we could stay behind the times and state that we didn't want to reinvent the wheel and we still want everything in paper. That wouldn't work. But obviously at the same time we're not reinventing the wheel regardless of whether it's electronic or paper we know what we want, when we want it, and to what level we want that information to be in.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Well obviously we'd have a… well certainly I'd have a different viewpoint in relation to coming from a purist quantity surveying background in that design alone, yeah, although it can make changes, it won't necessarily lead to changes in performance. It might in relation to the building but it won't in relation to how the project is delivered. And therefore certainly we wouldn't be measuring our performance by improvements in design, per se. Most of our performances, I hate to say, are measured on either financial or deliverables for clients.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response I think it can. I think it's important, yeah, the sooner that engagement happens the better. And mainly down to the word communication. The sooner everyone starts communicating better, the sooner those bridges are built so that going forward the communications are to a level that allows the quality design deliverable to be met efficiently and correctly and people are communicating adequately with each other so that they know they're interpreting everything correctly to move forward to create the correct deliverable.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response I think we definitely do. I think the process of reflection to us where we'd also just call it lessons learned. So lessons on all projects is key so that we don't copy and paste the same mistakes going forward. Do yeah, lessons learned on projects in relation to design, issues that may have arisen post contract with contractors so that you can mitigate those happening again. So it's always a continuing learning process.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response Yeah, we'd like to think that, yeah, we do all the above. I think certainly in order to work for the staff and it's also the type of work, so certain staff are looking for perhaps different type of work than others, some people like to get experience in public sector more than private sector, or vice versa. Or some people want to try to get into civils or other areas. So it's being able to have that mix of work so that you can reward them with the type of work that they want to work in, and then if it doesn't work for them to be able to switch them out into other projects where they do wish to work at, in order to make sure everyone's satisfied. And I suppose where we think we've got the inequality is that we've just got good spread and mix of work that we're able to give a variety of level of work to different people.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response Now, I'm going to skip question 25 and I'm going to go to 26.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response I suppose for us from a quantity surveying practice is we're still, to a certain extent, still reliant on 2D because we tend to do most of our measures in CostX, which is 2D format. I know where the main transition for us, and it's somewhat problematic, is getting measures from BIM and then whose is the responsibility for those quantities? So if we can't measure them and we're just taking them blindly from other people, are we bearing the responsibility for that quantum or not? Now, multidis probably less of an issue. But when we're not multidis and you're reliant on third party to provide the quantum from a BIM model, it then starts getting potentially a bit onerous as who's responsible if those quantities and quantum ends up being incorrect?

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response Now I'm going to skip question 27 as well.

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Well I think the very, very beginning of this is to maybe avoid projects where you believe that the brief is so poor that it's going to lead to lack of design, coordination, poor communication, where the scope is so poorly noted from the client that you're sort of nervous of working with that client because you're going to waste so much time sorting the poor brief out that perhaps on some occasions it may be better off not to do the work in order to mitigate that risk. Where you do take on… where perhaps the issue isn't the scope and the scope is reasonably defined, what you still end up with the primarily dysfunctions I think the most important thing is one, trying to force out where possible that clear design and scope so that there can't be people going off with different ideas as to what the deliverables are. Trying to make sure that those deliverables are set down as clear as day to everybody. And then ultimately it will come down to ensuring clear line communications with the client and cascading down to the team to mitigate all those issues in relation to poor communication, missing information, resource allocation, which all come down… which possibly can all come from nearly poor communication and clarity of scope, etcetera. Which once you mitigate those two things, I'm not saying everything else will go away, but you can certainly eliminate, I would say 80% of all the other items.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Project Consultant - Programme & Cost Control, Raymond Reilly (Researcher)*
Date/Time	*26March2019, 4.00pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*10 (Project Cost Consultant)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response The BS design process attributed to the mechanical and electrical element of the building. It is firstly an outline design based on what the clients expectation for the building are, which is developed in a stage basis with input from the end user, the maintenance team, and any stakeholders involved in the process. At each stage of the design development, this input from the team is developed and honed with 3 or 4 criteria in mind to suit the function of the building, namely the time that is available to build the project, the budget that is available to deliver the asset, and the level of quality to which the client requires. Other aspects come in to play such as legislative drivers which will shape the building in terms of sustainability performance, safety, and building regulatory control stipulations such as the BCAR guidelines.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response From my own experience, poor design performance can be a result of many issues, and can be as a result of issues seen on both the client side and the professional design side. The depth of detail within the design depends on the detail and directives given to the design team, as well as the time given to the team to develop the design correctly. Also, the design team must be properly resourced at each level of the team, be proficient in their associated role, and have the correct support network to do their work efficenciently. Quality control within the design team is important, and a checking protocol must be in place, as well as a 'lessons learnt' schedules from other similar projects, so that mistakes are not consistent from one project to the next.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response Academia is an important stepping stone into the professional world of design and other disciplines who operate in the construction industry. Graduates must firstly have an interest in the work of their future career and show some desire to learn from taught programmes. When entering the workplace, it is important to ensure that graduates have a team structure and guidance from more experienced professionals.

Within the college programmes the courses must utilise all the industry standard software that is used in offices which prepares students properly. Experience is important and colleges should ensure that there is a requirement for the student to get a placement within an office for proper exposure to office dynamics, teamworking, management, and generally what is expected of them.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response From my own time working within the construction industry, strong personalities and openness to communicate will result in a more successful career. Social skills, personality and communication attributes aren't necessarily taught in schools and colleges as one is graded on technical ability, but I feel these are arguably just as important. An equal mixture of both personality and technical knowledge would be the best outcome.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response I think this is up to the individual themselves, to understand what they want from their career, and if they want to be more successful, it will mean taking on more responsibility, and to do that it means stepping into a management role. This process will be assisted by taking appropriate courses and upskilling for this new role.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response This I feel is to some extent true. I think the main reasons or drivers for the contractor will usually (but not always) be financial gain, but for the designer there is more affiliation with the design and a sense of ownership associated with this. Perhaps this dissolves more when a contractor takes more ownership in the design in a situation where a different procurement route is adapted such as design and build.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response This is perhaps overlapped with Q2, although good management is advantageous, it shouldn't solve all engineering difficulties. Experience of the staff being managed must play a part, but also the unknowns at time of design, where not all designs can be fully watertight. Uncertainty will always be present in design because there are many variables relating to BS, but also because it interacts with so many other building elements of the project.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response It would depend on the individual and the professional experience and knowhow, but from my own experience good management can lead to good utilisation rates and efficient working. On a broader scale, good utilisation relates to company strategy, winning bids an positioning themselves in the right markets for bid success.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response I feel that because there is a high level of technicality and specialism in the BS profession, project teams rely heavily o BS engineers to assist the client with understanding what they want from the asset/project. Late design progress can hinder progress on say the architectural side for example, and as the BS element develops in a later fashion, it can impede the overall project design progress by introducing change and resulting in double handling the design.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response It is not relevant to all practices but perhaps there is a more relaxed approach to the design progression when the same company is involved across multi disciplinary design development. Standards might sometimes fall because what is missing is a subconscious effort to ensure that performance and outputs are maintained and aligned with other external practices.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response I think the management needs to be present over a number of spectrums, such as good inhouse management of staff, good external management of clients, and also focused on continuity of projects and workload. For all of these things, a competent skillset in BS management must be present.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response I think it is up to the individual to ensure that they develop their attributes continually and consistently. I would expect management to put in place the necessary teaching programmes and make these available to ensure that the individual can develop personal skill and business acumen. There should perhaps be a minimum criteria of learning such as core hours devoted to a particular topic of choice, but this is already in place as part of structured training programmes developed by professional bodies who set charterships etc.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response When a multitude of disciplines come together to deliver a project, each have their own criteria in terms of delivering their service. Often the long term view and health of a project may not be the main focus, but instead deadlines are focused upon, budgets must not exceed, and programmes must be met. Lifecycle costing is often an afterthought and should be brought into focus early in the design and hold some weight in terms of the value it can bring to the project quality over its project lifespan.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response This is true and is a result of greater quality of building design. New programs and software strive to make an impact on design, but with many design specialists, each developing software to assist with their own particular deliverable, the result is that coordination between each specialty might suffer. Having said this, there is also a benefit to several specialisms among the design team, but good coordination amongst all of these is imperative.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response In engineering terms I think the management and communication that pulls all the parties together to work in tandem is key. Each project must dedicate a role to an individual with technical knowhow. Failure in this area will result in poor quality design, and ultimately cost the client in the aftermath of the contractor signing the contract. A willingness amongst the team and treating each design discipline with equal importance will result will improve end product quality.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response Design coordination in my view is good communication, mindfulness of programme, awareness of workload and associated timescales, setting actions, knowing what the client deliverables are, and good technical knowledge in all disciplines and not in one particular area.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Gaps in design result in costs to the client. Awareness of contractual claims and commercial strategy from contractor will negate variations arising. Past experience might assist here and familiarity with 'typical' claims. Economic climate may dictate commercial appetite and so at times design deficiency is subjective. Having said this, a lot of time is often spent rectifying changes and agreeing costs for gaps in design.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response From a procurement perspective, getting the design quality and required design % completion correct is very important. Other factors such as design programme durations and fairness in allowing for the appropriate time needed to develop a design properly. By injecting a little more time and cost into the design stage, this might nullify expensive contractual claims.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response This isn't necessarily applicable to myself, but as a professional I try to build a database of information and develop it with each project that I work on. Perhaps this might be also relevant to the design profession, by using best practice designs and adapting any deficient design through continual correction and modifications.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response I havn't been involved in an opportunity such as this yet. TCD MV Upgrade maybe?

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response Outside of design professionalisms, the cost consultancy industry is measured on commercial acumen. This may be some things such as budget and cost planning accuracy, adding value to the client through identification of savings, rebuffing claims in accordance with good contract administration.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Yes I believe so, early and clear communication will endeavour to provide more accurate client representation of design, and allow the team more time to work on any issues that arise along the way. However, early engagement must also bring healthy interface between an informed and equipped client for design success.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Yes, I do this as part of my own development and professional competence.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response At a basic level, there has to be technical competence and familiarity with construction methods and building types. Good relationships in an office environment will overcome issues such as lack of time, lack of knowledge and lack of resource to complete a task successfully. Knowledge and experience added to this create successful working environments.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response N/A

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response Not necessarily applicable, but because we have an interface with design, and our day to day role operates on what a designer has produced, the quality of design is important, and production of 3D models have aided cost consultants as they provide visual guidance on intricate designs, but also can be used within cost measurement software. All professions in the industry will benefit from £D modelling in my view but because it is still a developing paradigm, weaknesses still exist.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response N/A

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response In the past mistakes have been made when issuing documentation to clients. To protect the business and to ensure that claims are not raised against our PI, quality management is introduced. Checking procedures are now used regularly, quantum and calculation checks, format and spelling checks; these are ll now done on a regular based. To ensure that efficient working and uniformity and consistency of service is there, libraries of information are set up. Guidance documentation and templates are used as the basis for the completion of tasks. Regular communication to the wider working team in Ireland means that teams can benefit from past experience on certain project types. Best practice procedures are identifies, and a formal and informal lessons learnt exercise is often used. Where there are repeat clients, knowledge of processes that worked and did not work are necessary to meet client satisfaction.

That concludes our interview. **END.**

Appendix 15 *Case study interview participant transcripts (External – SC professionals)*

Reference	*Engineering Management*
Attendees	*Lead Mechanical-Electrical Engineering Coordinator, Raymond Reilly (Researcher)*
Date/Time	*26th February 2019, 1.30pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*11 (Specialist Contractor Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

- ***i)*** ***the design and construction stage in the context of people, processes and technology, and***
- ***ii)*** ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Well I suppose the building services engineering design process is by it's nature a very collaborative process, I suppose because even within building services you've multiple disciplines. So for example in Ireland we would have mechanical and electrical but I know if you go to other parts of the world it's, within mechanical you might have plumbing, so there's all sorts of different subsections. So you have a lot of collaboration within that and even, outside of the building services disciplines there is a lot of collaboration with other disciplines, structural and there's interfaces with civil. So, it's a, in terms of how I best describe it, it's a collaborative approach from a concept, from bringing something from a concept through to completion and that's between not only production of drawings but also commissioning and reviewing documents that gives you a good quality building at the end of it.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response I suppose if we were sitting here we could probably write a book on it because there's plenty, there's a long history here, we been doing a lot of different projects here but certainly in the early projects there was a lot of unresolved design issues which would have kind of caught us, resulted in a lot of delays and cost, and incur costs when it came to system installation. I suppose it was poor design, not so much poor design as well as poor coordination but I suppose poor coordination is poor design and not being coordinated enough with other architects and other disciplines so, as I said it's a on-going issue and we've certainly, on existing buildings it tends to be a lot more difficult than on new builds because you are dealing with a lot of existing infrastructure and existing walls, so yes, it's a continual issue and it's probably something that we don't as engineers and architects, we don't really, we fall down on quite a lot.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response The first part I would say, that's probably a 'yes' and 'no'. I suppose when I would have left university I would have definitely said no, in that when I first landed in my first job, I would have said that what I learned in college, really didn't prepare me for what I was about to do. The benefit of hindsight over the last ten years, I would say, I would look back and say that it has in general prepared me quite well for what I do in terms of that the I suppose when I would have left college I would have felt that there was too much emphasis on technical work and calculations and the theory behind all the things that you are doing and not enough on practical but I suppose what I have learned is that you learn the practical really on the ground, you don't learn it in college, whereas the technical background that I have learned at college, you might not apply it for two or three years but then suddenly you might need to apply it and it's always there. Having said that I think there probably is, there's probably a potential to improve that, I think it could be probably more practical in some of the things you do in college and I think that certainly the university that I went to probably didn't keep up to date enough with the technologies and trends in the industry and I can't speak for it now, but I know say for example, when we were in college thermal modelling was the big thing, that was what was coming in and we were very slow to adopt that, we were still doing hand calculations when I don't think it probably wasn't necessary. So I think it really, if potential improvements I think it's just keeping up to date with trends and certainly in universities trying to be more innovative and coming up with the new technologies as opposed to being industry lead.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response I would say there's probably an element of truth in it. I probably would say that the 85:15 split is probably a bit much. Maybe I would say definitely, I can't speak for other industries but I would imagine in other industries that would probably be the case, engineering I think there very much is that, very much is a, that there's a huge percentage of maybe not the majority but a huge percentage of your ability to be successful is based on your technical ability, how it applies to my engineering team I would say, do I agreed that the statement applies? I would say that the, I would say no. I would say it's 50:50, it's certainly on an engineering level for the say the engineers it's definitely you need the, at least 50% technical ability and then 50% due to personality and ability. I think as you go up through the ranks, that's for say an engineer, if you are going to stay an engineer at a design level for your whole career, if you are moving up to towards into higher levels in management levels and definitely the percentage moves more towards your personality to get to those levels, at a base level from an engineering point of view I think it's not quite the percentages that would be listed there.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response I would say, I would agree with it but I would say that there is no, there's no real formal training to go to be a design manager but to me the best design managers, the only way you can become a design manager is by experience so I think while there is no, not necessarily any formal training, a good design manager is someone who has come from a design background, knows the in's and out's of design, I don't think it's something that you can train, I think it's just something that you have to get with experience.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response Yes, it's a case of I would have trained people from straight out of school to people coming in out of college. So its understanding people's capabilities and understanding of the industries and not to throw them in effectively the deep end too soon. Let them build confidence in themselves and the ability within the teams, but I have found the more time I do spend at the early part of taking on junior staff, I have reaped the benefits later on.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yes. On the last couple of projects I would have worked on, we would have had a risk register and we would have continual risk management workshops where we look at the different projects. Often it's not possible to reduce the risk to an acceptable level.

Certainly in existing, in live buildings there's a lot of constraints that you have to work within and as I say on new builds where there maybe site constraints that you have to work in, so it's, the other aspect of it that it has to be continual and there's no good doing, well in my experience that a lot of these risk workshops are done at the beginning of projects and then they are forgotten about and they don't really as a result they kind of fall away into the night and they don't have much impact so it's kind of something that you need to continually monitor.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response In my experience, managers have told you to do a job and you've done it the best way you can yourself. I'm not sure why that would have been, probably because of my age maybe, and the fact that I might not have been seen as a grad. Non-collaborative, would that be between disciplines though?

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response I would say it has got to the point where we are totally dependent on software now really, for calculations and there is, if any kind of large building, we couldn't do it without software even if you take the modelling software or the CAD but even aside from that, just from a straight up design point of view, all our pipe sizing and duct sizing is all done, none of it's done manually anymore, all our thermal modelling is all done manually so I would say that we would use a lot of, we would still use Excel which I would consider to be a manual calculation but really all of the kind of major calculations we're doing would generally be software based.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Yes. There's no doubt, and it's what you mentioned is one of the major one's is the BMS and the kind of interfaces and I suppose anywhere where there's a major interface between disciplines be it architectural or mechanical it's always something that gets during the design phase. Because I suppose you are working on your own element of the works and you know there's an interface in another discipline but it's kind of something that you are going to leave to the back until the very end and in the end it always does, it has to be done at some stage and sometimes you often find that if you have a good contractor they will kind of, they will know what your design intent is without putting thing down on the paper, so we often get away with it, which is not to say it's the right thing to do, or it's an acceptable way of doing it, I'm sure but it does happen and there's a lot of and certain elements of that there can be a lot of site work and a lot of more site inspections and things like that, a lot of work at construction stage to resolve those issues.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response I would say I would the example, in my last, in a previous job, if I say a good leader would be, a person who, on a couple of different skills will be a high level of technical ability, someone who you could feel that you could go with with any question, a technical question and who could answer it for you, if they couldn't answer it would certainly help you answer it or lead you through a solution. So that would be one aspect of it. A second aspect would be someone who would I suppose the nature of the industry is that there's always, I won't say people out to get you but there's always somebody. There's always somebody to blame and again it would be a person who would, who would have your back basically and would be defending you as opposed to, I have seen examples in, not in any of the jobs I worked with but on where, someone might go to a meeting and might blame someone back in the office for doing something and I think that's not good. So, those are the two main elements that I would see from as I said, someone that you could trust from a technical point of view and also a person who's looking out there. And as well as that, the third thing is to, someone who understands the restrictions that you to and gives you the time to do your work, they'd be the three elements. A non-blaming culture that's exactly it, that's what, maybe I didn't articulate that but that's exactly it. Yes.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly

related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response Probably not as quickly as much as I would like. I would generally put that down to and it's not, unique to where I am now I think it's across all the industries where there's just generally projects, project restrictions or work restrictions will lead to time constraints and there's a lot going on and it can be difficult to keep and I suppose if you have, if you are doing a design, it might be an opportunity to implement a new technology, often times you need the time to be able to go out and research that and calculate, do the calculations and have a background to it and often times, but the time mightn't allow it and you mightn't have the feel to do that either, so it's kind of trying to strike a balance to that but certainly it's, if I was to say that I was happy that I was learning at a rate I would say probably not

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response Not necessarily, I don't know. In my experiences, my managers would not ask me how, they would not tell me how to carry out a task, I would be doing a task and it's kind of up to me how I do it. So, there probably is quite a lot inefficiencies in how we do things.
I wouldn't say it's necessary down to out-dated industry or practice I think, as I said, I think the nature of engineering is that it's very much you kind of, you do it your way based on the standards and guidelines that you have, I don't think it's a case of where your, there's a set way of doing things and your told that that's the way you should do it. I think the nature of the industry and the nature of engineers is that you kind of come up with your own way of doing things you know.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response I would say, not currently I wouldn't experience that. I think in the current location I would see that everybody is quite spread across but in previous project jobs, I would have seen where people would be working in silos but I think the nature of building services, that it's a very, as I said with all the number of specialisms the nature is that you do, you are going to have to be specific. In things like BIM and thermal modelling and CFD, these are all very, they are all new things, it's not something that you can, I don't think you can have a 'one for all' engineer anymore, I think the building services engineering is getting too wide for that. I think people have to be specific to be able to do what they are trying to do to the best of their abilities.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response I think. I am not sure if it would be answering the question but for me the main thing in that type of work is for people, the other members of the design team and other people is to understand, well, why you are asking for something, what you need and why you need it. So, I suppose to use an example, if an architect changes the layout, straight away we would say, that architect's a pain in the 'you know what' because he's after changing the layout, but we don't know, he hasn't changed it because he wanted to, there's obviously, either it's client driven or there's a layout change so I think in terms of coordinated, if everybody is able to understand what the other person is doing and why they have done it,, not fully understand but has an understanding of that then I think that makes, if you can get everybody to cooperate and everybody realises why things he'd be doing, then things would get done a lot better.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response OK, well I think design coordination is being able to, on a continual basis to be able to take individual designs and marry them up as you work into one design which delivers a building or a project. And it's an on-going thing that has to happen on a continuous basis to completion.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?
Response I would agree completely with this statement. Poor design documentation leads to disruption and carniege at construction stage.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Yes. I suppose a couple of different ways to look at that even from a cost point of view, I have had numerous projects where, one particular project where I can think of where I ended up redesigning, it was a large building, 8,000 sq. meter offices and I virtually redesigned that, I virtually designed that twice because we were pushed to a tender date, we produced a tender date and we met the tender date but the project was way over budget so we produced a design, but the design wasn't in accordance with what the, we'll say what the budget was. Another example I would have, on a recent project where we, it was this particular building had, it had a structural steel package and a cladding package and an architectural package and obviously there is a lot of interfaces between those three packages.
There was a schedule came up where they decided that they would leave some of the design out of all those three packages to hit the tender date and then post tender they would coordinate it all with the awarded contractors for the three packages and it caused a lot of difficulty because, mainly because the contractor didn't realise that he wasn't going to get the level of detail that he would expect from a design and it caused a lot of delays, not so much cost but certainly a lot of delays yes, so, as I said definitely my experience would be that you have to go through a design process, you have to follow that process and you can't short cut it, you will get caught out eventually so.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response Yes. Absolutely I would say, if I take any of the designs that I have done over the past four to five years, I would say obviously there's often, there is many times where you have to be innovative and do thing, do new things, but I would say a large percentage maybe, 60% to 70% of the things that you do, you've done already and it's generally looking back over previous details and copying those details onto and obviously changing it you need to. But certainly there's a huge element of that in our work and I think an important thing is to have an up to date standards specifications that specifications don't change regardless from project to project obviously there is some specifics but in general there is a lot of information out there and you can, it makes sense to just reuse because you can't, it would take too much time to do it all the time.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response I would think that again it would depend on the project but I suppose the projects where I would have worked on where it was, it was building services engineering lead would be heavily service. I suppose I have experienced some working on project heavily serviced projects where the building has been lead by building services engineers and by structural engineers and other or civil engineers or other disciplines and generally my experience has been that the other disciplines don't have enough of an understanding of an experience of the building services installations to be able to come up with or to be able to manage the programme properly or even the design properly but having said that I am sure there's the same thing if you were to throw a building services engineer into management building a building from foundation through to roof you would probably find the same.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response As I suppose are you talking about like a performance indicator in the quality of your work? Or your ability to meet dates or? I can't say I have experienced performance when it comes to design management.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Not necessarily, it really depends on the client, I would say that if the client, I suppose it can work both ways. I can find that if a client who doesn't have a technical background who say wouldn't have the same mechanical background that I have I would say that that can often you would think that would improve the quality of design but that can often make the quality of design less because they have their ways of doing it and they have their opinions and they don't have the same. They don't know what your thought processes that you have gone through in a design and they are saying 'oh we should think things should be done this way or we want things done this way because that's the way we do things and that's the way I want to do it' but in reality that's not necessarily the best way to do it or the best way that the building might work. So, it really depends I think. If you have a client who's just focussed on the end product and you can have discussions with him on how to deliver that end product I would say, yes. If you have got a client who's probably very technically capable but and has their own way of doing things and I would say probably all that can result in relatively poor quality designs.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Definitely I think we're constantly when it comes to designs, certainly the type of design that we do within building services is that they are living buildings in that you know they are, you are dealing with different people have different requirements and the requirements are constantly changing so you have to kind of adapt your design yes and you know every engineer, every different engineer certainly in mechanical concentrated closed spaces has a different like for example my particular one from a technical point of view, to get technical. I don't like supplying air in below a certain temperature because I have been burnt on a previous project where I had to, where I designed it in accordance with what the recommended parameters are but for that specific office, it wasn't good enough and there was a particular people in there who weren't happy with it so as a result it's an area of design that I am quite sensitive to. So, it really depends, with different people I am sure, I could go to somebody else and they would be, have another area of a design where they might be very particular in. So, I would think that probably going back to one of the other questions is that yes, if you can get a group of different people together who all have their own individual areas of where they have, where they are quite sensitive or where they have a lot of knowledge on, if they can share or collaborate them then that obviously, that can lead to much better solutions at the end.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response I would say, the first point of it is the technically sound professional services I think there's a trend probably in the industry to now, to produce minimalist designs and push a lot of the design out to contractors on site, to vendors and things like that, I think that's, it's something that I have observed in the industry and that's doing and as a result it's making the industry very competitive and fees are very low as result because there is consultants out there and they are happy to produce that, I think what I would say in our team is that we, we don't do that we would produce good quality designs which are fully detailed and they are to the client's requirements, if there's, the other element I see is that, another quality is that we're, if a client wants us to come to site or they want to come and look at something we will do it. We are very hands on, very practical and we are on the ground, solving problems with the contractors and with the client, not necessarily always appreciated by clients but I believe that's something that we would do and as I said my anecdotal elements in the industry and from what I have seen of other designs that's not necessarily the trend.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response It's, I suppose when it comes to certainly mechanical engineering, if you are dealing with first of all you are dealing with people within a building and that a very variable output at the end. You are also dealing with weather, which is a very variable output too so, I think with any of these, these tools it was always the old mantra of 'dung-in, dung-out' and I think that applies but I think people certainly can be very over-reliant on them. Certainly when it comes to CFD's, I would have used previously in a previous company and people I would have, say for example, I did an office where we did a CFD and a lab test to establish what the velocity in the space was and I could tell you when we went to site that, not only was the lab test not anywhere near what it got to on site, but neither was the CFD either.

So, I think they are useful but certainly on CFD I am not convinced that it reflects the real world and, I a sure it does, if you put in the right parameters and if everything is in it correctly but it would be very difficult to get that, but outside of that I think for, if we talk about thermal modelling.

I think it provides us with a good guidance and we can say with a reasonable degree of confidence that it's accurate but at the end of the day you're relying on a lot of variables, such as people in offices, how they behave, how the building is operated, what the weather is going to be like outside, how the building is constructed, so I think as I said, it's 'crap-in, crap-out' and the accuracy really depends on that they're 100% accurate.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response A couple of things. I would say from a design process it can be more difficult in that we probably have to go into a lot more detail than we would normally if we take a coordination point of view. I suppose I would have always worked on the basis that I produce a design that can be constructed on site but I don't necessarily tell them how to construct it so for example I could show a duct going a certain route but if it doesn't go through the gap and it needs to be moved slightly on site, then you know that can be done on site whereas with 3D you really do have to produce something that, you are producing something and that's the way it's going to be built, you get your model, you give the model to site and it goes in as per the model. So that could be challenging and we probably spend a lot more time doing the design at that stage and the real challenge of that is that generally our fees haven't changed, our fees haven't gone up since going from 2D to 3D even though we have a lot more work. I would say that would be the main challenge.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response I would say I have had very limited experience on it. The only experience I've really had is when we produced some drawings in MagiCAD and the symbology wasn't probably up to scratch, there was a lot of, a lot of work had to go in to create that but again it probably goes back to what I was saying earlier on about the software, it depends on your inputs, if you need to kind of, it's all about if you put crap in at the beginning you are going to get crap out, so I, as I said I haven't worked with it directly but what I have seen, the guys who were implementing it on the ground that it does take a lot of background work to get it set up properly so that's, I think it does have, it seems to have the potential to give you good time savings and be very, a very useful tool but there is a lot of, there seems to be a lot of background work that needs to go in. it's not, it doesn't seem to be ready out of the box for all applications. But then again neither does Revit or BIM in general.

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response N/A

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Director - Electrical Engineering Contractor, Raymond Reilly (Researcher)*
Date/Time	*4th February 2019, 6.30pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*12 (Electrical Engineering Contractor Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response I'd say it's probably ad hoc at best, probably at best and depending very much on the different types of consultancies that you're dealing with. If you don't get a consultancy that's well used to dealing with building services, then you end up with very vague designs. And a lot of stuff that goes into probably stage five and six, stage five probably should nearly be in stage three or four**.**

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Well I very much agree with the trend, I think that items not fully closed out at stage four lead to a lot of misinterpretation and then doesn't become apparent until it's actually installed, and then people realise then that it's not right. And then you're relating back to, it's a battle then back to see where exactly the issue came along. But I think the… and it goes back to probably a bit of early contractor involvement, the actual… probably closing out on stage four designs should probably really involve some contractor or construction experience.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response So, the problems of the tradesman, I think, we are very much deviating from experience of a craftsman at this stage. But from personal experience dealing with graduates, the best graduate and the best engineering people that we can see from our end of it, is people that have served their time previously, or come through the apprenticeship, are fully aware of how services go together, and that's invaluable experience when they're carrying out actual design engineering works.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Yeah, I'd agree with that in that… people… again, it's probably back to something similar we have to stay with the experience that people build up over the years. And we can't be losing that, because… there is people out there that can put commercial aspects of a job together, commercial together on the back on fag box based on their knowledge. And while they're putting the technical knowledge to something that's obviously paramount in that that's the final detail. But from an overall perspective, it is the person's ability to be able to talk to people, communicate clearly that helps then in the negotiation process. You could be the smartest man on earth, but if you haven't got the personality to go with it, there's no point in trying to deal with people in the construction game.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response It's slightly related to the point above as well in the whole personality and ability to communicate perspective. It's a bit like, good soccer players don't always make good managers, when you transition from an engineer, which is doing as you're being told to do or asked to do or shown to do, to then transition across to managing people to do the same thing. It's not just only on your engineering experience then that's required, it's obviously your ability to communicate and lead people and get them to collaborate and come with you. So… there's an element of training required with that on its own, and it's probably all too often it's forgotten about.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response My thoughts on this is, going back to what we said previously on the stage four design, if the interaction between the contractor and the design team at that stage tells the kind of form, the final output from the design team, that it's a more constructive model I suppose than maybe would be the case if you had inexperienced, we'll say, or designers with not a whole pile of construction experience or workplace experience. That little things like a pipe doesn't do a ninety degree bend, it has to swing. A cable has to have a bend that's all experience from the construction site, I think is invaluable to help them close out on design before it goes to final release.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response There's a lot of difficulty in this, and especially if you had multi… or different design teams, or even on the same project doing different disciplines. Or even sometimes you'd see it where you have a full in-house design team, all the projects are… there's not a whole lot of communication between the different disciplines. And that's relating back up then to training of the manager who's looking after those, who's getting other disciplines to collaborate, so that when something is produced, it can work together, not just work on its own entity.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response I 100% agree with it and I think it goes from engineering right down to the last nut and bolt on a job. If the manager is not fully able to, or is not well able to communicate with the people on his team, well then everything will be lost and there'll be just so much misinterpretation of what's being asked to be done. But I think regular communication, looking for regular feedback from your team as to how they're picking up on what you're asking them, and actually then going right down to demonstrate what they're producing very early on is based on what you're requiring, you're not waiting for the end product and then saying, oh god, you totally misunderstood me there.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response Again, it's back to the actual quality of the design and the quality of the interaction between the design team and the construction team further along the line. It's very much like that… I think we're gone to an age now where if you don't understand something. Whereas, back in the day when people sat around a table at a weekly design team meeting on a project, and spoke about what the problems, what they thought the problems were. And then in that as well, you will actually… people will actually come up with the actual fixes for the problems.

Things could then be put into drawings or put into writing or whatever, but I think there's too much emphasis now on get the RFI out, measure the people on the days to get it back, and it becoming a nearly a them and us situation as opposed, as I said, the old days… not old days, but not a hundred. But the days of everybody sitting around the table and going through the drawings and going through the issues, coming up then with all the experience but it will be at a slightly… coming up a logical answer to the problem. And then just putting it into practice.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Yeah, I fully agree with that statement in that it is often brushed under the carpet and there's a perception that, if you have the one design team doing everything, or the one in-house team doing everything, that everything will be fully coordinated and in some cases it couldn't be any further from the truth, the kind of completely separate silos. But then it just relates back to the manager again to pull them together. But I would fully agree with that statement.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Well I suppose I spoke about it at length in other questions, but the management is just the ability to be able to bring your team together and get the most out of them, by involving them in the process from the very start, allowing them to express their innovative ideas and coaxing them then to come to the table with solutions rather than problems. So it's a… I think it's just the ability of a manager to be able to make people feel part of the team, as opposed to just doing something for the team.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response Well I suppose it's back to a graduate scenario, we would have a lot of… every year we bring in a certain percent of graduates and starting bringing them up through. But again, we… there's a special graduate programme put together for them that actually incorporates stuff, both inside work and outside of work. From not just learning on an engineering practice but learning on a whole professional development. So that's how we manage to bring that along, is we have a programme in place, we ensure that it's rigidly stuck to in that, and that sets out from a remuneration package, right up to the learnings from as I said both inside and outside the actual engineering perspective.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response So, my experience on this one when it happens, and it does happen, not maybe all too often, but is that the issues don't come to light until they're actually in situ, and then that's when it costs lots of money to rectify the situation, where it's probably going back to what I was talking about earlier. The more experience, practical experience you can get into a design, the less chance you will have of this, and it's obviously a lot easier to fix a problem when it's on paper first of all, than it is when it's hanging out of a ceiling near the end of the project life cycle.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yes, we definitely would have experience with this issue alright, for sure. And actually, the concerns about moving forward is based on, we'll say even say graduates and younger people coming out now. Their ability to communicate across multidisciplinary, or even across from person to person, is very much limited to this. But all developments now in the whole social media mobile phone issues, so there's no… I see it with graduates coming through, their face to face conversation, they're not fully equipped with those skills because they haven't been brought up with them. And everything is text someone or send them a WhatsApp or an Instagram or whatever it is. So I think that's actually going to be… apart from multidisciplinary, actual between person to person is going to become a bigger issue as time goes on.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response Well I suppose the statement itself is very true, it is a major aspect of engineering practice. If people are designing in silos with like… in the commercial world that we live in, people want rentable space, they don't want massive areas above ceilings or in risers for services. So it's all about working together to see how we can utilise multidisciplinary brackets and all other sorts of aspects of trades and all that sort of stuff. So they can be brought back down to minimum because the developers now simply don't want to be allowed space to be used for anything else only letting space.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response I suppose it's the ability of the design team to engineer together and produce something that will produce a design that will utilise the minimum amount of space. Again, going back to what I said about developers, that instead of people just designing in silos, saying, that's my airflow, that's the size of the cable, what's the size of this, no one… to look at the overall picture and to minimise the space because it's just not there anymore. So the more coordination that can happen at this same stage, will only be when it comes to stage five and six.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Well, I 100% agree with the statement that problems allowed to get to construction stage… then they cost a huge amount more to fix. We've carried out several surveys of this down the line and one being the percentage of time or cost to fix something picked up at design stage and another then at coordination stage and another…. The cost of fixing something at design stage would be it's hours, but if it goes to construction and allowed to be constructed, you're talking about tenfold the time required to fix it.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Well it always happens, it's something that's part and parcel of construction, it's the end date doesn't change and by if again design is not fully signed off at the different stages along the way, all that's going to happen is it's going to get pushed. And then you also have the issue we spoke of before, we arrange stuff and we're designing things that become apparent along the way. I think there's probably not enough project time to allocate to reviewing the processes along the way, it's all about, get it done, get it done, get it done. So I think until we start looking at a bit of time to review the different processes and allow the review to take place and the amendment to take place before we start rushing into the next stage, that's probably going to continue to happen.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response We have I suppose, in that, we try to get the information, we try to hold back as long as we can. What we're actually doing now is, we're getting involved earlier on in the project for items that's coming further down the line, it's kind of working out the minimum of six or eight week look-aheads that allow for… not that it's much reinventing the wheel, because that generally to happen when you're trying to do things at high speed at last minute. We need people that look ahead and see the issues and have time to try and sort them out, then you'll find that it's just the most logical approach and the most simplest way of fixing things.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response It's actually probably… it's a better option from our experience, in that, when you have a building services engineer leading the programme, they then are probably better in tune with the time scales required and the coordination required to get a job completed, as opposed to, maybe a CSA or an architectural-led who all they really focus on is getting the building up, getting it aesthetically looking well and then just firing the building services or into it there somewhere to just get it working.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response Well performance is measured in ourselves in the ability to, first of all, take the original design, coordinated through and then get it… produce the end product within the time allowed, to the client's satisfaction, within budget. So that's probably how it's performed. Changing along the way is probably not so much something that we're… our end of the market was probably more in the step three… or the phase three, or the stage three or stage four of the design. But it's predominantly measured in, I suppose really client satisfaction at the end of the day.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Oh yeah, absolutely, yeah. I think it's critical that the design team and the client are fully in line with what's actually the end product. And I suppose a model is probably a good way of showing that going forward, in that, the client can actually see first had exactly what he's going to be looking before there's a screw put in the wall. So I think that will help hugely in that. But it's fundamental to a quality output, because if the design… if the client and design team are on the one level, it leads to less requirement to see something in situ before saying, well I like it or I don't. I think the BIM model going forward will very much help that process.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Yeah, very much so, yeah. And I think a good manager definitely would have to be a reflective type person, in that they can look at what has happened along the way, see how things can be improved and then be willing to incorporate those learnings for continuous improvement. I think that's the fundamental ingredients for a good manager.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response So a lot of the things that I put together would be based on, I would bring people together and I would rate people on maybe my own ability to do things. So I'd relate to how I do things myself. So I think it's important that you bring people together, that know exactly what they're doing. And that the different qualities and the different attributes definitely lead to unique… like, you can't have all people of the same mind on a project, or then you won't have the bit of interaction, or the bit of questioning each other that would be required. Everyone has to have somewhat different opinions, but probably the same end goal.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response I think they're fairly accurate, but I think definitely a lot of it is down to the actual experience of the person using them as well, to be able to interrogate what the output of these decision making tools, so that they can be double checked. Because I suppose, like any tool is only as good as the person that's using it. So it definitely needs to be… they are good, but they definitely need to be a good level of experience working with them, is the ideal scenario.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response So, the big challenge there was actually literally the training of people. So when 3D modelling came out first, I spoke to a person back a good few years ago, and their analogy was that it's the same jump from actually pencil drawing to AutoCAD, it's similar jump from 2D to 3D. So again, it was a huge training process. But again, going back to… from a contractor background, we found that getting tradespeople, training them through the process of modelling or AutoCAD or whatever, CAD 3D, whatever we were using..they were a better… there was a better output from them at the latter stages, because they just knew again what will fit and won't fit, and how you can actually draw something into a building, and what you need around it regards access again to services. And what you need to get at and don't need to get at, and that made a difference of the layering from the top down as to how they put the services into the building.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response N/A

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Yes, we would have, I suppose not solely related to design, but actually leading to construction. But just to go back up a little bit to the centre section there, inferior quality of installation, that's probably the effective end of it that comes to… or the most effective part that comes to our end. Because again, it goes back to, it may not even be inferior quality, it may be that the installation is fine but it's actually… what it's perceived to be wanted for in the first place, is inferior, and that's probably a bigger issue. Time delay of installation, that's an age old problem; schedules are so tight now, that any reworks or any re-design or any kind of inferior quality, it's going to be massive. Increased cost of the installation is related to the others, it's… again, the end date doesn't change, things get forced up against a block wall, so you're then into acceleration and extension of time and all that sort of stuff; that's where things get out of hand. And it can… what we found in the past and how we've come to kind of help prevent this sort of stuff, is again, it's just interaction and the experience of the construction team at the final stages of design. Which I said already, I think the big model is going to be huge in going forward in… I won't say eliminating, but definitely reducing the amount of time this occurs, drastically. Because you can see the end product is there, the 3D models, it is so good now that you can do a walkthrough, flythrough, whatever you want, and you can actually see exactly what you're going to be looking at, at the end product. So people don't have to wait until they move into the building for a week or a fortnight to see exactly how things work for them, it's a lot easier.

That concludes our interview. **END.**

Reference	*Engineering Management*
Attendees	*Director - Mechanical Contracting Lead, Raymond Reilly (Researcher)*
Date/Time	*25th January 2019, 1.30pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*13 (Mechanical Engineering Contractor Lead)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

- ***i)*** ***the design and construction stage in the context of people, processes and technology, and***
- ***ii)*** ***the design-construction interface.***

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response One which is ever evolving.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response As engineering & construction are intrinsically linked; a delay in the design results in the delayed procurement of a particular piece of equipment, further leading to postponed install, testing & commissioning.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response Speaking from my own personnel experience, I believe having site experience enhances ones design ability. I believe a work placement scheme should be introduced to help facilitate this. To form part of a final year course requirement.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Current management is aware & would agree with this statement. As such, an open positive form of communication is encouraged. The removal of the traditional 'blame game' has been replaced with a team resolution approach.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap

Response Time & correct project exposure will assist with the technical knowledge requirements but social element may have to be teased out via company in-house training programs, led by HR. Were certain KPIs are set out for potential candidates.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I would agree with this statement. This highlights what an important position the role of MEP Coordinator is. An individual who acts as a mediator between the two. This also highlights the requirement for more of a focus on communication abilities in addition to technical competence when recruiting. Communication is a topic which needs to have as much emphasis as any other corner stone topic in an engineering course.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response I can see how this would occur if the right candidate is not in the right position. Luckily, the current projects have been overseen by time efficient decision makers which have reduced issues. However, having a single source or only the one decision maker can & has led to delays.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response All managers should look for early feedback from the candidate to ensure that the message was received and interpreted correctly. This could be in the form of a 30/60/90% feedback on the task, based on its complexity.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response This does happen but is not necessarily a negative aspect. As the project progresses, the very nature of the project and how it is achieved needs to be reviewed & change if required.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response People by nature focus on there individual task & tend to overlook the bigger picture. More of a focus on the project devilry as a whole apposed to individual disciplines is required.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response Someone who has the ability to say 'No'. Someone who will endeavor to meet challenging deadlines but will not compromise on quality to do so. Someone who can communicate, motivate & negotiate.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response Recognizing this is an important factor within any thriving company, Kirby have appointed a dedicated 'Competency Assurance Mentor & Coordinator'. As a company we set high value on annual CPD and Chartership Status for individual engineers.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response. Current climate building trends of aggressive schedules and tight margins are forcing progress over quality, which subsequently results in an overspend in both time & money. Some companies are still trying to save on the front end, instead of resourcing efficiently from the start.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response An open form of communication is a culture strongly encouraged throughout the company which helps reduce barriers created by people working in isolation.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response Maintaining a respectful work environment, one which recognizes that a healthy work-life balance is required. Developing a close knit team encourages the 'all for one and one for all' attitude, which benifits the company (project team) when faced with looming deadlines.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response Design coordination, is the overview of all that is required to bring a Client's vision from concept to completion.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response The earlier the Contractor is evolved/appointed the more time for joint review & collaboration. Giving the contractor a chance to review & provide input into the design ensures continuity in pricing against what's specified. Thus removing the need for a Contractor to do something perfunctorily so as to save time or money.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Placing progress in front of quality ultimately results in additional time & money at the back end of a project. Occasionally, time increases will be made to allow for design development but the completion date remain the same, resulting in a squeezed install or commissioning program.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response Ensuring the right information is given to the right person, ensuring it's received and understood. Trying to limit information overload (cc'ing everyone).

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response As Data Centers are heavily serviced, the majority of the project would fall under the Building Services. In this circumstance, having the BS.Eng manage the program, demonstrate a good understating of the sequence of events.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response Key Performance Indicators (KPIs) are outlay-ed during an annual review. These would cover the three separate areas and identify what level of competency the individual is currently at & how they would progress in each. These would then be quarterly/annually, based on HR policy.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Yes. The earlier both are appointed the better for both. It will result in a more detailed final design from the Consultant and give the Contractor a degree of comfort, knowing that all items have been priced for.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response This is a practice that is implemented throughout all company projects. As part of our internal close out documentation a joint (Contractor/Consultant/Client) lessons learned matrix is developed at the end of each project. Identifying items, causes & possible solutions in future projects.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response. As Construction can be a stressful environment in which to work, the open communication culture which has been developed within the team makes for an enjoyable work environment. This in turn aids to positive mental health of individuals within the group. Having the understanding that a healthy work/life balance is to be maintained.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response These softwares are a good resource and provide much needed support during the design process. But an understanding of the basics is required to analysis the results generated by these softwares to ensure no human errors occurred during data input.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response The flow of information in order to generate the model is normally an issue. Drawings are generally required in advance of final design and/or equipment approval, resulting in much to be interpolated.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response *Declined to respond*

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Similar to the BIM it provides much need support. The issue is trying to marry both the Technician & Engineer into one role, developing the skill-set of both. Apposed to the traditional two man team.

That concludes our interview. **END**

Reference	*Engineering Management*
Attendees	*Electrical Contracting – Cost Control, Raymond Reilly (Researcher)*
Date/Time	*3rd March 2019, 2.30pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*14 (Electrical Engineering Contractor – Cost Control)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response Yeah, so I think I suppose initially that when the design is completed and sent out, it's for tendering only. It's only about – I don't know, would it be about 80% complete and there's coordination with other designs, like structural and civil element?

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response Yeah, so I have seen this in the past where again everything is down to timescales. The engineers are probably under pressure to get these packages out. To design stage to let contractors tender for it. Then when we do get the site, as I mentioned in question one there is issues with coordination. Obviously, there's clashes with other designs like structural. So, there is processes in place to sort these out, but – like RFIs or whatever. But they do end up costing money in the long run.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response So, I think engineers have spent three or four years in college, like quantity surveyors or any other one that wants to work in construction. I think it's better if you work more like the trades guys, as in you spend maybe four days in college, one day – sorry, four days on site, one day in college. I think that works a lot better, from my experience anyway. Even as you said, a guy coming from a trade background, they have the experience in the trade but it's from the other end. If you've spent three years in college, yeah, you may be good at computers and know all the technical information, but the day to day running and the problems that happen on site, you mightn't be up to speed on that. So, if you could split your time between, I suppose college and site, I think that would be a way of improving it.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response Okay, yeah. So, I suppose the QS. A lot of QSs, they wouldn't have the detail behind everything. Mechanical or electrical QSs, unless they've done a trade background, they wouldn't know how long it took to wire a light or a plug. They do work off norms. And so, in some cases yeah, you can use norms. There are a lot of other cases you can't. You're depending on your foreman, your project manager to fall back to provide information. And I suppose the QS just gets a brief description of what happens, and he has to try and get paid for it.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response Yeah, I'd say… Yeah, I suppose if there was a detail course on coordination and drawings with other design teams with the civil, structure, and architectural teams just to try and get everyone working together and singing off the same hymn sheet.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response Yeah, so I suppose again a lot of the – from my side, a lot of the design engineers, they'd be working out of offices. They don't see the day to day running of a job and the amount of headaches there and the amount of little problems that the engineer wouldn't know about. I suppose if the engineers spent time on site with – if they could work on site, they'd probably see more. But then again, that's probably not feasible, but if they could see the day to day running of a site, it probably would help things.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response Yeah, I'd agree with this. So, I suppose if you could engage with the construction team at an early stage. I suppose the guys who'd be building the job. That would help. Or even better again, if you got them involved in the design while you're designing the job. I suppose, speak to the guys who are going to be building and what way they'd do it. I suppose the more heads you get around the table, the better it will be. But again, that probably takes time, and maybe something you don't have.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Yeah, I'd say 80% might be a bit on the strong side. But I have seen in the past where managers pass down their so-called dirty work to the engineers or whoever is under them. Even though a lot of the time they're swamped already. And I suppose when you're trying to do your own work and then picking up pieces for someone else or helping someone else out, this results in you being put under more pressure and probably there's going to be more mistakes made then.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response Yeah, so I suppose I've seen people go off their own bat and I suppose if there was a problem, they wouldn't try and fix it then. They'd just kind of push it down the road, and it just never really works out.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response. Right, yeah. I do agree, there's often a division. Yeah, I don't know. I don't really know how to answer that one.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response I suppose interaction and communication. And in my experience, probably it would be the key element. Because if you have a team around you, you need to constantly communicate with them. And I suppose if you set a good example. If you work hard and put the hours in, put the effort in, your team will follow you. But if you're just kind of – don't really care, don't show interest in it, I suppose it does have a knock-on effect with your team.

Question Nr 12 Question twelve: due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response Yeah, so I actually – yeah, I agree with this. In the company I work, we have a number of different ways of sharing things or of lessons learned on different projects, but we have this system now. The SharePoint system. So, basically the whole company, you just log into it. It's only the company, employees of the company, have that access to this SharePoint. So, any projects you have, if you come across problems, you just put them on this where other people can see down the road. Lessons learned. And it's well filtered, so if you're working on building services jobs that – I know a lot of them are bespoke projects, but if you have issues, you might just put it on SharePoint saying, "I had an issue with this. This is how it was resolved". And people down the road then might look at it and go, "Actually, we don't want to make the same mistake on this. We'll do it- "– they would have seen it on the SharePoint, there was mistakes made. So again, in the long run that probably saves money. And we also have another thing called Yammer, I think it's called. I don't use it too often myself now, but it's kind of a bit like Facebook or one of them things where again you just – it's kind of an app you have in your phone. And you just update if you're on sites and you see stuff, you can upload pictures and whatnot to this app.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response Okay, again I've seen this in the past. So yes, the main thing is probably capture the problem as soon as possible or try to rectify it as soon as possible. Because I've seen issues happen where it's just been kicked down the road and it's something that – it mightn't have been kicked down the road. It might be just missed, and you come to commissioning stage then and there's a big problem and it's – unfortunately, this falls back to the design team and solely on the design team. So again, it costs a lot more money to try and rectify it. I suppose if the designers had the time at the design stage, this issue mightn't have occurred.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response Yeah, so I think a lot of building services jobs, they're once off buildings or bespoke buildings with different requirements from clients. It would be different if we were building 100 apartments that are identical for a client that is constantly building apartments all over the city. But a lot of these building services are bespoke. And also, I see different clients. You could be building a job for an American client. They might have different requirements. You could build the exact same job next door for a German client, but it's meant to be the exact same job, but they have completely different requirements and ideas. But even though it's the same building, but that can lead to problems.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response Yes, so this – yeah, I suppose this is very important to deliver projects and again, I go back to communication with your team and engagement with the whole team and trying to get everyone on board at an early stage just to get it done.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response Yeah, so the design coordination is – I suppose from commercial it's often – it's a word I don't really like. So, there's often arguments between engineers, clients, whoever. You have the design coordination, then there's design change. So, I suppose to establish what is what. So, in my opinion, a design change is obviously – if you're asked to put in a helicopter pad, it's a design change. But design coordination would be if the length of a cable extended 100m, you might have to increase in size. So, I think that would probably fall under design coordination. Yeah, it is one that is kind of a tricky one.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Yeah, again from my point of view I try and track this as best I can. Now, them figures look a little bit high to me. But I do agree that there are problems in this. And I suppose, if the design team interact or engage with the construction team throughout, it would reduce this. There is ways this can be done through RFIs and whatnot, but it is important to get everyone involved and get the construction team and the engineers working together at an early stage to try and get these problems sorted as early as possible. Because the longer they go on, they will burn more hours to get rectified.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response Yeah, I agree 100% with this. And I suppose, in the real world time is always – there's pressure on time and everyone's under pressure to get things done as quickly as possible. And unfortunately, they do lead to problems.

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response Yeah, I suppose I don't know on this one. But my opinion, just keep it very simple. There's no point trying to overcomplicate things. Drawings change, just update the drawings, issue drawings through the proper agreed format. It's just when – if it's all kept off board, it should be pretty straightforward. The problems I found anyway in the past is when stuff is agreed on walks and drawings are updated and then you're expected to do the work, and then there's argument if it's not right then. "I told you at such and such a date to do it this way or do it that way". But I think it's just keep it very simple. As I said, updating drawings, issuing them through the agreed format or whatever.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Right, yeah. To be honest, I've never really seen it. It's usually – it's the main contractor with the help of the MNE contractors as well. But I've never seen solely engineers running it at all. It's back to the main contractor.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response Yeah, I suppose there's a number of different ways you can measure performance. Obviously, if a project gets completed on time, in budget, and without any major incidents with health and safety or whatnot, and quality is good, I suppose that's good. That's obviously going to look good. But I've also seen within our company where the difficult projects that people worked in. One of the above elements, like the mightn't make money, but there might be really, really a difficult project where the design is very poor. I think in my opinion, I think these guys are – they should be getting highly praised for this, because these projects are more difficult than the ones that have the nice design.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response Yes. 100%. I suppose if the client can be involved at an early stage, and I suppose again if the client decides exactly what they want. Because probably no more than yourself, I've seen where clients at the beginning of the job, they give you a job brief. They say yeah, I want this that and the other. That's fine, you go away, and you design it. You design it, you set up the pricing. They mightn't look at it again. Next thing happens you're in construction, no, I don't want that, I want this. Even though – so, if you could get the client engaged early on and get them to sign up to our design and that they're happy and that any changes will be a variation or whatever.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response No, I wouldn't be reflective anyway. You don't really get time in this game for that.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response Yeah, so I suppose the last project I've been involved in. The key element was the guys I worked with were very – they were honest with each other, which I think is huge. If a guy knows something, he wasn't going to do it. I've been on other jobs in the past where guys aren't honest and then they try and do something and next thing they make mistakes and it ends up costing you a lot of money then. So, I suppose communication, hardworking, honesty, would be.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response Yeah, to be honest, I wouldn't have ever used this, but I've heard about them. And from hearing, I think they are a massive help, but I don't think they're 100% accurate. Again, I'll go back to building services projects. There's a lot of different elements and there's a lot of these buildings are bespoke, so there's a lot of things to consider. Where this software, you mightn't be able to feed it all that information.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response Yeah, so this all seems to be an argument on construction sites over the last couple of years. I suppose, the so-called younger guys on site who have been kind of brought in using BIM and they've done BIM in college are familiar with it. But from a guy who has been in the industry for a few years, there has been a huge transition period to go from 2d to 3d. And it's barely a couple of years ago on a job, there might be some guys were using BIM, other guys would be using 2d. And then you're trying to compile them all together. But I think it's definitely – it's turning more now to everyone is on board with BIM now.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response N/A

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign.

As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Yeah, I suppose this is kind of a tricky one. It's very hard to budget costs to allow for this, but in my experience, it does allow a little contingency there for scope gaps, design development, whatever you want to call it. So, if you could get the client to sign up to what you propose for it and make it as clear as possible to say this is what you're getting. And this is what you're paying for. Any deviation from this, and if it's not picked up in your contingency. There is always going to be changes, and you'd be hoping you'd capture these changes within your contingency. But if you can't, you have no choice to go back to the client to seek further funding. Even though it's not – no one likes doing that. But unfortunately, money talks and if you don't have it in the pot, you have no choice. You have to try and fight your corner.

That concludes our interview. **END**

Reference	*Engineering Management*
Attendees	*Mechanical Contracting – Cost Control, Raymond Reilly (Researcher)*
Date/Time	*11th March 2019, 4.30pm*
Venue	*Adelphi Plaza, Dún Laoghaire*
Participant Nr	*15 (Mechanical Engineering Contractor – Cost Control)*

Raymond Reilly is writing a thesis for fulfilment for a doctorate degree in the built environment. He is conducting an investigation of engineering management in his building services engineering practice. The inherent lack of engineering management at design stage (poor design quality, design standards and installability) leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate practice dysfunction in terms of redesign and associated financial burden.
The study drives its importance from the effective role that engineering managers can play in design consultancy practice. As a primary research method, structured open-ended interviews will be conducted with key engineering disciplines, allowing them a reasonable opportunity to present phenomena in their own terms.

This engineering management research will principally focus on:

i) the design and construction stage in the context of people, processes and technology, and

ii) the design-construction interface.

The primary purpose of this research is educational, however, the research findings may assist in improving the design process in building services engineering practice by understanding practitioner experience. OK, so I am going to go through each of the questions and please gladly respond in an honest and professional manner.

Question Nr 1. How would you best describe the building services engineering design process?

Response So subject to release of information there is not for an ER piece, an early integration ECI solution there so we would like to vet the design ourselves at an early stage there just to ensure that from a pricing point of view that we get some cost surety for our times there with our overall price. And we don't want the situation there where we're building claims, we're protecting against them. So we, at the moment the on projects is the lack of design development and the programmes tend to be compressed so that's where we need to get involved early with the design, just to get some cost surety and pricing surety for the client.

Question Nr 2 Ineffective design management results in extended design timescales and the production of poor quality tender documentation, any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. Explain how your professional experience relates to this trend?

Response I agree I suppose that the designer lease is quite late on a lot of our complex projects that we undertake there and that's why we have to get involved in design as early as possible ourselves to come up with a design solution. So we often put on, we have our own design engineering team in house and we support the clients construction management team to get a resolution there that we may or may not get paid in that design and we might come up with some of the solutions. But what it does is it definitely, we find the extension of time piece, clients still want to work to the same end date so our programmes are being compressed so I'd say it's really, it's about teaming up with the right main contractor there as well to make sure that we can work to the programme timeline so, yeah.

Question Nr 3 What was once deemed the province of a craftsman, now demands the services of a body of highly-educated and specialist-trained professional engineers. However, it is unfair that academia alone does not form a solid foundation for engineering graduates in the building services engineering field. Has the Irish engineering education system adequately prepared you for practice? Can you identify potential improvements in academia to produce better prepared graduates?

Response From the engineering point of view, as I mentioned, our engineering director would have designed roles and responsibilities for an engineer. So an engineer goes down a few separate routes, he might be a turnover engineer, a commissioning engineer or a project manager. So to decide from an engineering point of view which route he's going to go, we bring our engineers, we have a graduate programme internally for the last number of years and our engineers, we move them around different business units and different projects here to get varied experience and decide which route is best suited to that particular engineer so they become of three, one of those three options. So they do, it's important that the engineers don't spend their time doing document control, we bring doc controllers in for doc control and engineers do their own job and what they're trained to do so they're highly valued in the business.

Question Nr 4 Recent research shows there's 85% of financial success is due to your personality and your ability to communicate, negotiate and lead, whilst only 15% is due to your technical knowledge. Explain how this statement applies to your engineering team?

Response I suppose financial success, what we do internally is we price out our projects and we set up a proper planned structure for a project, how we're going to actually build it. So we work around constructability reports. We've done a lot of, what we have designed is best practice within the business. So the key function is operational, scheduling, commercial and our engineering falls in under our operations there as well. All those functions there, they have clear R&R's, roles and responsibilities, on our projects. Once we, I suppose financial success is only one side of it here, I suppose operational, financial success falls out of, on the back of operation and delivery so if we can't operate and deliver our projects, we will have a problem on the financial side. Technical knowledge is really key, early engagement there again to map out any design issues and get our projects moving. So technical knowledge is really key across all our teams so I'd say financial success falls out on the back of operational delivery for us as a business.

Question Nr 5 As a building services engineering professional there is limited or no guidance from the transition from building services engineer to design engineer, sorry, to design manager. How do you foresee bridging this gap?

Response I suppose internally what we've done is we have mapped out, we spent a lot of time around process mapping there in the last 18 months. So we have mapped out the QA, QC role within the business, the design engineering managers role. So if we have, between our pre construction heat and our large projects that is, where pharma, pharmaceutical type projects are very fast track whereas the likes of data centres would have a window for pre-construction and design review so we tend to look for a four week design review in our complex projects that we can vet the design. The design manager meets the team there so it isn't just the engineering design really, there's, as I say, there's, you have the, you have to get all together and everything else there, your turnover packs need to be developed. So that all needs to be set up during the preconstruction stage. Again, we've clearly mapped out that there's only one key manager for each role so our engineers fall back in under our projects, our PM's are responsible for the delivery of our projects. So the R&R's are designed, the outlined R&R's are designed, everybody has R&R's, our engineers have R&R's on their projects feeding back in through the PM's so they have a functional responsibility. That can change on a project by project basis, depending on the engineering role.

Question Nr 6 Engineering is increasingly being recognised as a technical and social process. Indeed it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief also suggests a dissonance between the design and construction professionals, hence the need to improve technical and social dualism. What are your thoughts on this statement?

Response I suppose it just goes back to working as a team, once they get clear, again clear roles. The engineering design piece is where we support our clients. We need to understand the clients requirements there. And we generally don't, like we won't take on any business, we wouldn't performance design unless they get conceptual design. So the appetite to take business for purpose within the business. So our engineering design ultimately is reviewing technical documentation there and we do a technical and commercial validation of the information] so I suppose that's how we operate as a business.

Question Nr 7 Design is a difficult process to manage and needs effective planning and control to minimise the effect of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy but from managerial complexity. What is your experience?

Response That's obviously correct. We need to ensure the design is completed by an end date. To allow enough time for commissioning the back end of our projects we need to have a set of design deliverables and close out dates so that's the key, it has to be planned out yeah.

Question Nr 8 It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. Do you agree with this statement, and how do you envisage such communication problems may be improved?

Response Historically, I'd 100% agree within our business the now roles are clearly defined, engineers know what their expectations are on a project by project basis. So you have to plan out your deliverables and just to see the piece, your engineers are part of that delivery.

Question Nr 9 The building services engineering design process is found to be a major source of problems for the subsequent project phases. Even to the extent of undermining management during construction. What is your experience?

Response I suppose are we talking, I suppose in this case I'd say problems stem from the generation of the ER's, the employers requirements, day one. And the technical engineering piece, there could be gaps so this is where we would have our own engineering managers within the business on the electrical and mechanical side to do a vetting of the complex engineering review and it's important to carry out that review process. Design is never there I suppose really but the performance piece is we don't want to carry the risk of performance there, we want to link in that technical review and a gap analysis there yeah.

Question Nr 10 Dissonance between designs in an multidisciplinary practice is often brushed under the carpet at design stage. How do you relate to this phenomenon?

Response Yeah, I suppose the key, the key of working as a team is an understanding, a concept of design. So we need, look we need to understand again the employers requirements and we need to review the drawings and we need to look at the plant going into the project, any key notes I suppose across, drawings or any key notes across. But the key here is working with the client side and the client's construction team to understand what they, what I suppose their deliverable is I suppose, what performance criteria is set out, what date is actually set out on the plan itself and what our role and expectations are so again it's working as a team.

Question Nr 11 Successful building service engineering design management needs management; excellent interpersonal skills are imperative. What is your understanding of management in a building services engineering practice?

Response It goes back to your, it goes back to question seven there where you're asking about managing complex design and waste, one of your earlier questions there. So we need to plan out what needs to be done and somebody needs to lead on that and we need a leader and a manager so the leader will look at the overall process and the manager will make sure the activities are open and closed there because if you don't have that, it's highly unlikely you'll be successful.

Question Nr 12 Question twelve: Due to commercial and time constraints, practices are often unable to meet learning targets within formal training programmes. And as such, resort to informal training programmes. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is in organisations skilled at creating, acquiring, interpreting, transferring and retaining knowledge. How does your practice learn at a rate that gives you a sustainable professional advantage?

Response What we do again with any of our key projects here to ensure we don't make the same mistakes twice, we do a lessons learned piece in all our projects across all the different functions just so say what worked well, what didn't work well and what learnings need to be incorporated for future projects so that's available on our drives within our business. The other piece is where we bring in during our engineering meetings, our group engineering meetings, we bring in an outsource, other businesses there whether it is I suppose manufacturers, systems, we bring in sectors there to do a bit of a training module day. And we also then, I suppose internally we would have our engineering manager would have a development process mapped out for each of the guys within the business in each of the regions. So they would be learning off the managers, they would be going on our complex projects and they'd work as teams on the projects. So we might have one particular project at the moment, we would have three engineers learning from an engineering manager in all the different functions on that particular project.

Question Nr 13 The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage and consequently dysfunction in practice. What is your experience during the project life cycle?

Response Okay, again this is a collaborative piece there. It's the design team, it's the design . We need to find some way of getting everybody into a room to meet the end dates for design before we can start construction so the preconstruction piece again. We, there's only so much you can compress on a job and you're still going to need your six or eight weeks at the end of a job for your commission so as long as it doesn't compress your commission piece. There might be some flow to compress the construction piece of the project. So if design overruns, construction is compressed and you still need the same amount of time for commissioning. So if you run, if you don't get the design complete, you'll end up overrunning your construction and your commissioning will overrun at the end of the project so somebody ends up paying and it's most likely the client.

Question Nr 14 The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in siloes, which provide further challenges. Has your team experienced this phenomenon and what are your concerns for future multidisciplinary design?

Response I suppose peer R&R will sort that out so I suppose when you have problems then, without people understanding their role and their responsibility for any particular project and deliverables for a project where we're going to be working in a different direction so I'd say just R&R's is the answer there.

Question Nr 15 Technical co-ordination, in the context of building services engineering means working with and influencing other members of the design team. So, they conscientiously perform necessary work in accordance with a mutually agreed schedule. In your professional experience, please articulate how co-ordinating technical work of other people, by gaining their willing co-operation, is a major aspect of engineering practice.

Response So what we need to do is we need to programme out the design deliverables and we need to map that back into the overall programme for the project so we can overall integrate the programme. We need a manager to manage each of the steps along the way and to coordinate that so there is that, there is that skillset there where we can communicate properly to people and we can manage people's expectations and deliverables. If we know there is a gap, we can need to support that gap with other resources to get it done. So the coordination piece is to ensure that the people that are doing the tasks are capable of doing the tasks and to understand that deliverables are going to be met. But there's one point of responsibility I suppose in that case and that's the engineering lead.

Question Nr 16 Design co-ordination is a purposeful and goal-orientated activity which aims to co-ordinate all service design activities, processes and resources in building services engineering practices. What is your interpretation of design co-ordination?

Response I suppose we need to look at phase delivery again through our programming deliverables there so it's what are the key deliverables first that need to be achieved, that large procurement that we need to close out. And design around the plan so procurement can be placed and then the secondary services around that can be managed. I suppose we're looking at offsite fabrication across the industry and we're looking at then solutions there so how do we design and coordinate through a model there. So ownership of that model is really key early on and it's best that the services managers own that model from the start rather than through the CSA site or architectural site because there will be gaps in the end.

Question Nr 17 It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practice. It is estimated that an additional 40 or 50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. What is your professional experience thus far?

Response Okay, so I suppose in this case we're looking at two different types of work hours, are we talking about the management and hours, pre-construction hours to resolve design deficiencies so it's really key that we get an early designer who can take up to four weeks in general on a project maybe up to €10,000,000. And then the bigger scale projects will take more time, more people, more resources. I wouldn't think it would affect 40% to 50% of the direct labour hours because that can all be managed by offsite fabrication and onsite, it just needs, it needs a total review. So the constructability strategy needs to be decided during the design review phase as well so it's really important that design and construction are together.

Question Nr 18 Design issues cannot be resolved by squeezing the design process, achieving milestones with less information, or making explicit decisions to change the design process. What is your experience of this phenomenon?

Response I suppose time is time so if there's only a specific amount of time really to close out design, we need to I suppose use our own experience internally to see what we think it's going to take to close the design gaps. Again, if we have no control over design, we can only set a list of deliverables and put it back into our programme and if they're late it's going to affect the overall project. If we can control design and can get involved at an early stage, we can support deliverables there and we can provide teams to support that. So I feel milestones, it depends who owns the design**.**

Question Nr 19 Information management is concerned with ensuring that the right information is available when required, in the right format. Has your team adapted a non-reinventing-the-wheel approach to your design?

Response Yeah, look we have a best practice mapped out there. So again we would have standardised expectations, we have engineering managers across our different business units, different projects here so it's having the right person lead it. Not reinventing the wheel is where you have the experience driving on the engineering management and engineering lead there. So it all feeds back to an overall engineering director anyway so it's lessons learned, the key is lessons learned, don't do what we, don't lose out where we lost out before and learning best practice and implementing best practice.

Question Nr 20 Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. What is your experience of being involved in a project where the building services engineer led and managed the programme?

Response Project managers need to lead the programme. The engineering, the engineering piece needs to form part of the programme but needs to be mapped out but your programme needs to be managed by your project manager, your project manager, not your engineering lead. The engineering lead feeds back into the project manager and has his own set of deliverables as has the construction lead and the construction managers, site managers, project managers that go into an overall project, whether it's a project manager or a project director, depending on the size and scale of the project. But the engineering lead needs to lead his piece to make sure the overall project works.

Question Nr 21 Performance measurement provides a means of distinguishing between perception and fact at three levels – individual, project and organisational. A significant question for a design performance measurement is whether improvements in design alone, can lead to change in performance. How is performance measured in your practice?

Response So, you know, in the business we have an overall strategy map within the business. And the type of projects we go for, they need to align to the business overall strategy at business unit level. Performance then is measured on a KPI basis. And I suppose on an individual basis it's measured on KPI's and deliverables at senior level. On a project level, it's measured on roles and responsibilities being delivered which again maps up the KPI's, maps up the overall business strategy. On a project level, progress is measured by deliverables so the dates on delivery, actions. We'll always have problems, the nature of construction is you will have problems along the way and it's how we resolve those problems together. So it's open close status on a project, you have to close the loop. And then on the delivery of the project, I suppose we need to manage the progress of the project itself so we need to constantly manage the progress. So we measure it at a level I suppose really from a cost point of view and we measure it from an operational point of view on progress and delivery. So it's about making sure all our change, the change that goes on in a project is measured back through our programmes again so everything needs to be managed through an overall programme from a project delivery and a KPI and roles and responsibility level and then on an individual.

Question Nr 22 Early engagement between the client and the technical design staff during the design process. In your professional experience do you believe this communication correlates to the quality of design-deliverable output?

Response 100%. But again it's down to the quality of the design team on the client side. If there's a weakness there, that weakness needs to be escalated at senior management level to get it resolved. Or sometimes there's secondary conversations with the client there just to say that this isn't working, you're not going to get your project delivered and we need to do a designer view on your behalf and support that design side. It's not about that, it's about the project getting finished. At the end of the day, if we fail to, if we fail to deliver a project operationally, everybody is going to get hurt so whether that's reputational damage or commercial or cost damage, you know, nobody comes out shining.

Question Nr 23 The process of reflection in engineering design, is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. Do you consider yourself to be a reflective practitioner, that is to reflect on your design, so as to engage in a process of continuous learning?

Response Nobody knows everything so I suppose from my own commercial side I need to understand technically how we are going to, how we are going to build a project. So the money piece falls on the back of understanding first so if you have any issues, you need to understand it in time, I have an issue here. So you actually need to understand constructability, you need to understand the design at a high level. So designers, everybody learns off each other so you work as a team, you get multidiscipline into a room and you do a full constructability review continually. So continual engagement all the way thought the project will support personal design so you need a right leader there to manage that.

Question Nr 24 A successful building services engineering entity achieves client satisfaction, provides technically sound and professional services and maintains a supportive and rewarding working environment for its staff. Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.

Response So again, I'll just pick, I'll just pick, I suppose my function in the department in the business there so that's commercial. I would have, I would have quantity surveyors, I would have trades people, I would have engineers working within that department alone so it's multiple viewpoints, there's always four or five angles to a situation there. Nothing is as black and white as we always might think so it's good to have different personalities and different perspectives. So where you have the PM's, the engineers, the planners and the QS's working as a team together it works quite well. And then we obviously do our own kind of, we'd have our own legal and contracts review which is a different piece and a different engineering understanding I suppose so it's working as a team, a successful working environment.

Question Nr 25 The use of design decision-making tools, for power, lighting, lifts, heating, ventilation, wind and solar energy may be useful for guidelines. In your professional experience how accurate are decision-making tools in your specialism?

Response We'll keep it fairly simple, we'll take the first one, the power distribution. I suppose at the end of the day you will get cabling, plant area. You actually do your own calculus and your own measurements there to see have you undersized or oversized cables. So I mean emergency lighting, lighting we'll be checking ourselves and I think depending on the employers requirement. So we need to do a design review on their requirements and we need to look at data sheets and technical information there and see where there's gaps so it's all about gap analysis there. There are tools there which is also the experience of people and there's the practicality of what the client is looking for and design might be over designed so again it comes down to the clients budget. But yes there are design decision making tools, I suppose that's people's experience.

Question Nr 26 Building information modelling is not just a fancy 3D model, it is about moving away from the traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. Describe your challenges during the transition from 2D to 3D modelling during the design process?

Response Okay, so we have, we have a very strong engineering piece that falls in under our engineering management as well. So we model, again we model most primary services on our project so we prefer to own that model because we have a lot of confidence in delivery. So when you own the model from the start yourself you can deal with clash resolution there through the model so it avoids a lot of operational clashes there and rework on the site. The 2D to 3D, I suppose the 2D is just to get constructible drawings out to the team so that you can mark progress and you can understand what's to be built. The 3D piece is you always need to look at a live model to understand where the primary services are, secondary services, all that kind of stuff may not be on a model. Your plant should always be mapped out on the model and how you get from, how you get from the initial point out to the field point here, I suppose from plant to your field devices there we just, you know, it needs to be mapped out quite well. We also need to do kind of point out scanners of the rooms to make sure that the room dimensions match the model dimensions which we have historically found not to be the case. And it might be midway through a project that that develops there so it's an early learning, you need your point out scanners there to make sure. Again it's about clash resolution, getting, your model is really effective, the new modelling piece is really effective for design coordination and construction coordination.

Question Nr 27 Magicad offers integral BIM 3D software for building services engineering design. It is a powerful enhancement tool, developed to save time and more user friendly, flexibility, intelligent and parametrical user-environment. How has your experience been thus far?

Response We use Revit, Revit ourselves anyway primarily there. Our design, our BIM manager would have to answer that one there, he uses different software.

Question Nr 28 Inefficiencies in engineering practice at design stage are noticed as follows: Lack of design co-ordination between disciplines, poor communications, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision making and poor design quality. As the design process is found to be a major source of problems at construction stage even to the extent of undermining management, the following deficiencies are identified. Inferior quality of installation, time delay of installation, increased cost of installation and redesign. As a direct consequence of these deficiencies the impact in design consultancy practice is significant. The primary dysfunctions relate to professional dissonance, poor design quality, redesign programme and redesign costs. How has your organisation dealt with this practice dysfunction?

Response Okay, so professional grievance, poor design, redesign programme and redesign costs, I suppose this is, this is where early constructability and design comes into play again. So it's on a project by project level so we need an early designer too on every project and we need to put a design team if the construction, or if the client has their own design team, construction management design team. We need to do a review and a gap analysis and open up a risk register and is that going to impact time and quality. We don't want to have quality issues on our project here because that's complete rework. We don't want to go back and redesign and find out afterwards that we ordered plant there where we carried the performance risk on plant, we need to make sure that the plant is fit for purpose where it falls in under our remit. Constant progress, redesigning programmes, programmes are, we need to get an agreed baseline programme right and then we put our change management through that so is that design change, is it design development. There's always going to be a design development piece so we need to allow some level of float in our programme for design development and the client needs to understand that so it's how that programme is communicated back to the client. So are we overall taking on the GCCM role or is that communicated through the client's team. So it's important that goes all the way back to the client so the expectations are clear. So we can only bring it back to the construction management team in many cases but the actual client needs to understand that for his own budgeting costs. So you're talking about redesign costs so we just need to do feasibility studies constantly on design. If there are gaps, we need to put a budget against that, is that people costs, is it planning costs or is it actual design engineering costs. So are we doing, are we doing structural studies and structural reports so it depends on the size of the design we're actually doing there but they all need to be managed individually and all that through a programme and deliverables list. I suppose that's how we deal with it.

That concludes our interview. **END**

Appendix 16 Case study interview analysis (Internal – BSE practitioners)

NR	INTERVIEW QUESTION	PARTICIPANT 1 *BSE Practice Lead*	PARTICIPANT 2 *Mechanical Engineering Lead*	PARTICIPANT 3 *Senior Mechanical Engineer*	PARTICIPANT 4 *Project Mechanical Engineer*	PARTICIPANT 5 *Electrical Engineering Lead*	PARTICIPANT 6 *Senior Electrical Engineer*	PARTICIPANT 7 *Project Electrical Engineer*
1	***How would you best describe the building service engineering design process?***	➢ Logical thinking ➢ Problem solving ➢ Fulfilling client aspirations ➢ Dislike in repeating design strategy ➢ Design variability to maintain interest in discipline ➢ Problem solving	➢ Design process is iterative and collaborative ➢ Multidisciplinary approach ➢ Option engineering to hone out the best solution	➢ Design process variance between practices ➢ Different quality assurance and quality control procedures from practice to practice ➢ BSE design process is not streamlined compared to other fields ➢ Significant steps to standardize BSE design process	➢ Concept to practical detail design ➢ Extensive multidisciplinary collaboration and technical coordination ➢ Multidisciplinary BSE coordination ➢ Adopting BIM to ascertain practical installability	➢ Design process takes cognizance of design, installation, monitoring and operation of BSE systems	➢ A highly multidisciplinary communicative process to produce design documentation to on-site installation purposes	➢ Understanding client expectations and subsequently defined a clear brief ➢ Continuous collaboration between all disciplines ➢ Perception that design development is acceptable at installation stage; a never-ending process
2	Ineffective design management results in extended design timescales and the production of poor-quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. ***Explain how your professional experience relates to this trend?***	➢ Practitioner inexperience ➢ Lack of mentorship ➢ Lack of appreciation of site constraints ➢ Onerous on contractor to resolve - *fill in the gap* ➢ Additional fee expenditure ➢ *Pure design* warrants *pure thinking.* ➢ Front-load design stage to improve BSE practice at construction stage	➢ Design management needs to be effective from the outset and continued through all project stages ➢ Decisions made at design stage has a direct correlation at subsequent stages ➢ Accurate practitioner direction is required from the outset to ascertain tasks for all stages	➢ Inaccurate design workflow in practice impacts compromises design quality and programme at construction stage	➢ Ineffective design management instigates legacy rework at construction stage ➢ Poor delegation from management to practitioners ➢ Inadequate communication of design brief and programme ➢ Unrealistic deadlines conveyed by management at design stage ➢ Time constraint leading to inferior design ➢ Unresolved issues to be addressed at construction stage	➢ Lack of communicating relevant design data ➢ Time constraint leading to inferior design ➢ Lack of design peer review ➢ Cost of design change at installation stage is a multiple when compared to rectification at design stage	➢ Time constraints in the BSE design process lead to the exclusion of critical client expectations ➢ Construction programme constaints also lead to inferior installation ➢ Reluctance by design management to request addition time at design and installation stages to complete thorough design and installability of unresolved issues ➢ Additional installation costs contradicts value for money for the client	➢ Inefficiencies at design stage are only realized at construction stage ➢ BSE design development is perceived as a rectification tool during installation
3	What was once deemed the province of a craftsman now demands the services of a body of highly educated and specialist trained professional engineers. However, it is inferred that academia alone does not form a solid foundation for engineering graduates in the building services engineering. ***Has the Irish engineering education system adequately prepared you for practice?*** ***Can you identify potential improvements in academia to produce better prepared graduates?***	➢ Universities focus on teaching undergraduates how to think and conduct processes ➢ Holistic design approach is missing ➢ Narrow-mindedness of graduates ➢ Limited practical understanding and appreciation for BSE design ➢ Employed to mentor graduates from day-one	➢ Practitioner refers to university taught first principles whilst engaged in design optioneering ➢ Practical experience was limited during the initial years in practice ➢ Bridging the gap between academia and practice is imperative to successful design practice ➢ Practical experience during academia would enhance the initial years in consultancy practice	➢ People drive practice as opposed to their respective qualifications ➢ Consultancy means working well with people ➢ Intellectual capacity and higher degrees do not warrant good practice and healthy client relationships ➢ Personality superimposes academia in BSE practice	➢ Theoretical design is priortised at university with limited taught-management skills ➢ Client negotiation skills is paramount is practice but not priortised for undergraduates at third level institutes ➢ Taught management is key for career progression	➢ Significant gap between undergraduate training and real BSE design practice and subsequent installation	➢ Inadequate training for BSE practitioners ➢ Excellent academic knowledge but lacking site experience and interpersonal communication skills	➢ Academia does not prepare practitioners for BSE practice ➢ Apprenticeship in conjunction with academia is an excellent standing-stone to prepare graduates for practice ➢ Significant learning curve for new graduates relating to client and multidisciplinary engagement and site experience
4	Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead whilst only 15% is due to your technical knowledge. ***Explain how this statement applies to your engineering team?***	➢ Practitioner-Client connectivity ➢ Undiplomatic practitioner approach ➢ Recruit for the practice, not the role ➢ Goodness-to-fit in a team as opposed to the role ➢ Poor practitioners fragment the team, create friction and weak with clients	➢ Technical knowledge is vital at initial professional levels, where personality is key when practitioners rises the ranks to management level ➢ Technical directorship should not be confused with management	➢ Technical initiative and people abilities are key to practice success rather than solely technical knowledge	➢ A technically competent manager with good interpersonal skills is imperative for successful delivery of quality design	➢ An effective manager is deemed key to successful project delivery as opposed to inherent practitioner technical knowledge ➢ Clear management delegation to supporting practitioners is imperative at design stage	➢ A well-balanced BSE team include management with technical background and excellent interpersonal skills supported by practitioners with technical savviness in design Standards	➢ The Irish BSE industry is confined and interpersonal skills are paramount to work efficiently with other disciplines ➢ Technical issues can be resolved easily, personality conflict is detrimental to project delivery

5	As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. ***How do you foresee bridging this gap?***	➢ Management lack of understanding of the design processes ➢ Lack of understanding of other discipline design ➢ Leads to poor technical coordination ➢ Greater appreciation of other discipline design ➢ Ideally design managers have experience working in multidisciplinary teams	➢ Best design managers have the technical know- how ➢ Default career progression to design management ➢ Formal transition process with enhance a design management role	➢ Introduce management modules in university curriculum to bridge the gap from design engineer to design manager	➢ The engineer-management transition is subject to bespoke variables ➢ Management is not an expert in the multidisciplinary field of BSE ➢ Trial-and-error process transition	➢ BSE design practice is business oriented with project management and technical knowledge at the centrefold ➢ Management modules introduced to university curriculum would bridge this gap	➢ BSE management to posess hands-on-deck quality with excellent communication skills ➢ Management to understand both design and site complexities ➢ Tacit and explicit knowledge tranferrable to practitioners	➢ Transition involves self-learning with trial and error ➢ Adopt a self-management strategy that works best for the inherent design manager
6	Engineering is increasingly being recognised as a technical and social process. Indeed, it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between design and construction professionals, hence the need to improve the technical/social dualism. ***What are your thoughts on this statement?***	➢ BSE designers can have an over-simplistic view to a solution ➢ BSE designers can unnecessary overcomplicate issues ➢ Contractors can steer solutions from a more practical stream ➢ Bridging the gap between BSE practitioners and contractors will produce better solutions	➢ Practitioner-client relationship is complex; clients' technical knowledge varies from project to project ➢ Practitioner technical savviness may conflict with non-technical client – outcomes are perceived differently ➢ Dissonance is managed by a clear mutual understanding of the end-goal	➢ CIBSE facilitates the integration of designers and contractors to lessen the inherent technical and social gap	➢ Competent practitioners design conceptually for concrete practicality at installation stage ➢ BIM adoption bridges the gap of conceptualization and concretization ➢ Practitioners design solution to take cognizance of safety and practicality of system installation ➢ Contractors' method statement informs practitioners of practicality issued of systems' installation ➢ Designer and contractor relationship are key to the quality of installation	➢ Design is deemed intangible, whereas design is tangible from an installation contractor's perspective ➢ Disconnect between BSE practitioners and specialist BSE contractors	➢ BSE specialist contractors forced to adopt design-oriented BIM model – a mini- BSE consultant per se ➢ Contractors developing a design mindset ➢ BSE designers to be wholly cognizant that their design must be installable from the outset to alleviate dissonance between design and construction professionals	➢ BSE contractors tend to take a black-and-white, right-or-wrong approach to BSE design interms of installability, which potentially raises dysfunction in BSE practice ➢ Practitioners are design focused while contractors are cognizant of design changes that warrant additional costs – unaware of subsequent BSE practice dysfunction
7	Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy, but from the managerial complexity. ***What is your experience?***	➢ Day to day issues require a traditional ➢ Innovative approach required for complex design ➢ Better planned process ➢ Resource allocation is key ➢ Ideally led by an experienced multidisciplinary design partner ➢ Experience is foresight	➢ Project complexity correlates to effective management; the more complete the project, the greater intracity in managing the project ➢ Experienced professionals deal with complexity more effectively	➢ Managing the design process is imperative ➢ Mismanagement of in-house technical expertise and design programme initiates issues at construction stage	➢ Artificial intelligence will not replace practitioners ➢ Project complexity arises by large multidisciplinary teams with different targets, milestones and design considerations ➢ Management competency required in the key project discipline	➢ Unclear and unrealistic client expectations leads to inferior design with significant delays and cost at construction stage	➢ BSE design approach varies amongst practitioners and from practice to practice, thus its complexity	➢ Design briefing gets lost in translation from management to practitioner ➢ Time constraints and multiple project demands can initiate managerial complexities
8	It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. ***Do you agree with this statement? How do you envisage such communication problems may be improved?***	➢ Default management positions ➢ Complacency in the management process ➢ Lack of foresight to over-design and unnecessary deliverables ➢ Lack of awareness on cautionary repetitive design	➢ Direct correlation between the efficiency of assigned tasks completed and between practitioner experience level ➢ More prescriptive tasks to less experienced professionals	➢ The role out of new digital technologies has been sporadic leading to miscommunication of design intent ➢ Tacit/explicit experience of senior practitioners does not take cognisance of modern design methods and building information management	➢ Unpaid work in practice due to inefficient design ➢ Change management is key to tracking deficiencies at installation stage ➢ Good management to communicate a succinct design brief taking cognizance of project variables ➢ Clear communication to other disciplines in terms of frozen model, and impact of subsequent changes	➢ Improved design planning with adequate resources allocated to attend focused client briefings meetings with subsequent inhouse debriefing	➢ BSE practices shoe-horned in unrealistic design programmes leading to undue pressure in practice and inaccurate design ➢ Complacent management coupled with competitive fees and inadequate design programme is a recipe for waste in practice	➢ Unclear direction from management initiate inefficiencies in design ➢ Consistent workflow is hindered by underskilled practitioners ➢ Duplication of effort is often evident when practitioners and technologists conduct the same task manually and digitally

9	The building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management during construction. ***What is your experience?***	➢ Individual incompetence ➢ Lack of understanding for installability ➢ Lack of appreciation for end-user requirements	➢ An unclear design process leads to lack of coordination and inferior design solutions ➢ Poor design data impacts cost and programme at installation stage ➢ Peer review is often subjective as they are not wholly aware of design considerations	➢ Design stage has a knock-on effect on subsequent stages ➢ Issues are easily resolvable at design stage with negligible impact compared to resolving at installation stage	➢ Client value of BSE design practice ➢ 80% design accuracy with 20% resolved at installation stage	➢ Participant declined to respond	➢ Direct correlation between a squeezed design programme and inefficiencies and deficiencies at design and construction stages, respectively	➢ Design development at construction stage by a collation of BSE specialist contractors and practitioner input is perceived to resolve design issues
10	Dissonance between designs in an multidisciplinary practice is often brushed-under-the-carpet at design stage. ***How do you relate to this phenomenon?***	➢ Misconception that multidisciplinary practices are more collaboration ➢ Potentially more collaboration between non-multidisciplinary practices	➢ Dissonance is generated through lack of responsibility for overall design coordination in a multidisciplinary team. ➢ Leave until a later date is often forgotten leading to a snowball effect at construction stage	➢ Various levels of technical coordination between disciplines leads to dissonance, particularly whilst managing the BIM process	➢ Ability to communicating BSE technical design to other disciplines ➢ Defining resolutions and consequences ➢ In the absence of management, practitioners tend to feel accountable for their respective design and brushing technical coordination with other disciplines under the carpet	➢ Dissonance instigated by time constaints and complexities with technical coordination	➢ The multidisciplinary nature of BSE and its cog in the overall design team wheel initiates dissonance by default	➢ Practitioners operating in a silo environment leads to technical coordination issues at installation stage, which incur contractor and BSE practice costs
11	Successful building services engineering design management needs management; excellent interpersonal skills are imperative. ***What is your understanding of management in a building services engineering practice?***	➢ Setting parameters by way of performance ➢ Adequate resource allocation, motivation, commitment, understanding and ethos ➢ Connecting the right people to the project ➢ Self and practice reputation ➢ Embrace collaborative, supportive and comprehensive ➢ Easy to work with leading to a satisfied client and repeat work ➢ A safe pair of hands to deliver client's demands	➢ Technical management is imperative ➢ Technical competency is key in BSE practice ➢ Directing BSE practitioners to the right technical solutions ➢ Lack of interpersonal skills leads to practitioner avoidance in approaching their managers	➢ Management by example ➢ Technical ability and interpersonal skills ➢ Managing client expectations ➢ Good at working with people	➢ Management demands succinct understanding to defining a clear project brief, delegate tasks effectively, and stipulate achievable deadlines ➢ Transparency on real deadline without concealment ➢ Understanding the limitations of the BSE team ➢ Trust practitioners to deliver	➢ Management demand inspiration guidance to create a team that works well together ➢ Allows practitioner adequate time to complete tasks ➢ Leaders advocate blame-free environment to encourage team spirit and engagement ➢ Empathy to practitioner personal situation	➢ Management who possesses both tacit and explicit knowledge in the BSE industry are ideal candidates to lead a BSE team ➢ Cautionary due where management is solely university educated without the practical know-how	➢ Management demands foresight, which is clearly communicated to practitioners ➢ Direct practitioners to successful project delivery ➢ Advocate a non-blame working environment
12	Due to commercial and time constraints, practices are often unable to meet learning targets with formal training programs, and as such resort to informal training programs. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is an organisation skilled at creating, acquiring, and interpreting, transferring and retaining knowledge. ***How does your practice learn at a rate that gives you a sustainable professional advantage?***	➢ Training and mentoring to a qualitative level making practitioners feel valued ➢ Complete transfer of knowledge from management to practitioner – *the mentored needs to know what the mentor knows* ➢ Equipped for more complex projects	➢ Large multidisciplinary practices have an advantage by offering practitioners global reach ➢ Leveraging knowledge from specialisms located globally ➢ Learning by collaboration rather than trial and error	➢ Modern BSE design philosophy is often enhanced by continuous professional development seminars and workshops which are hosted by industry professionals and professional institutes ➢ Formal training is challenging due to time constraints ➢ Practitioners to learn at their discretion	➢ Formal training preferred with trainer accountability ➢ Professional institute facilitated with certified continual professional development training ➢ Caution with informal training due to miscommunication and misguidance	➢ Project demands hinder formal learning ➢ Knowledge transfer to junior practitioners is challenging due to project time constraints	➢ Large practices have online training modules with annual practitioner targets ➢ Ideally BSE management to set practitioner targets ➢ Practitioners to take responsibility for their training and career path	➢ Self-learning under design demands with limited resources is commonplace in BSE practice ➢ Online learning facilitates practitioners to develop their skills ➢ Adopting a learning in-action is paramount in BSE practice at design stage
13	The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage, and consequently, dysfunction in practice. ***What is your experience during the project lifecycle?***	➢ Silo design or *designing in packets* ➢ BSE design is not a truly iterative process ➢ Caution in adopting/augmenting previous designs – possible negative impact in subsequent project phases	➢ Shortcomings in design are normally discovered at installation stage by the respective contractors ➢ Shortcomings in mechanical design are often discovered at operation stage leading to inefficient buildings, thus dysfunction in BSE practice to rectify the design issues	➢ Continuous collaboration between disciplines at design stage ➢ Complete technical coordination at design stage minimizes risk at construction stage	➢ An inadequate collation of cost and management leads to practice dysfunction ➢ Front loading the design process reduces risk at installation stage	➢ Health start at design stage is imperative for successful subsequent stages ➢ Resource planning is challenging due to other ad-hoc project demands	➢ BIM adoption will improve collaboration in a multidisciplinary environment ➢ Multidisciplinary teams are well educated, talented, skilled but with different mindsets leading to miscommunication ➢ Close collaboration unleashes disparity	➢ Inefficiencies derived from silo-working environment ➢ Lack of collaboration and miscommunication between disciplines catapults BSE practice into dysfunctionality

14	The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos which provides further challenges. ***Has your team experienced this phenomenon, and what are your concerns for future-multidisciplinary design?***	➢ Silo-tendencies in larger multidisciplinary practices ➢ Smaller BSE teams tend not to rely of external specialists ➢ *Total* design is deemed more efficient in smaller practices ➢ Inherent knowledge of other specialisms by practitioners to better implement the greater design	➢ Irish BSE practices tend to blanket design in their respective discipline ➢ The introduction of stringent building regulations leads to difficulty in general design; default specialisms are emerging	➢ Traditionally BSE design was viewed a 'dark-art due to its multidisciplinary nature ➢ BSE practitioners have a broad spectrum of knowledge on inherent discipline design, as opposed to siloed discipline design in many other countries	➢ Practitioners to be accountable for their design and overall technical coordination with other disciplines	➢ Specialisms in BSE practice are increasing ➢ Inherent BSE disciplines depend on specialists' input to progress design – resource allocation is paramount to this workflow delivery	➢ Practitioners' lack interpersonal skills with tendancies to work in silos ➢ Different projects demands different people with different skillsets leading to the silo phenomena ➢ Practitioners design strategies are inconsistent by adopting hand mark-ups, 2-D AutoCAD or 3-D BIM	➢ Silo-working appears indigenous in BSE practice ➢ Management to act as a single point of contact for all BSE practitioners ➢ Clear communication and project transparency between management and practitioners
15	Technical coordination in the context of building services engineering means working with and influencing other members of the design team so they conscientiously perform necessary work in accordance with a mutually agreed schedule. ***In your professional experience, please articulate how coordinating technical work of other people by gaining their willing cooperation is a major aspect of engineering practice.***	➢ Partial implementation of design with constant technical coordination with other disciplines ➢ Ongoing live connection between disciplines to mitigate against rework ➢ Collaboration between design disciplines is imperative at design stage to avoid deficiencies at construction stage	➢ Mutual understanding of the client brief by all disciplines ➢ Lack of understanding leads to frustration between practitioner disciplines, and ultimately time inefficiency ➢ Explain what, when, how and why particular design need to be addressed, and the inherent beefits of this strategy	➢ Limited practitioner personnel attend client meetings to understand their expectations ➢ Thorough understanding of the brief by all team disciplines will lead to design issues downstream ➢ Early technical review of project deliverables to BSE practitioners to ensure multidisciplinary adherence	➢ BIM adoption facilitates live technical coordination ➢ Practitioners to be cognizant that other disciplines' teams have different variables - team dynamics, different management, different resources allocated to the project.	➢ Technical coordination with architectural and structural constructs is challenging due to the dynamic nature of building design ➢ Mutual agreement by the full design teams to freeze the model alleviates an uncoordinated design output	➢ Technical coordination is perceived as a BIM exercise where practitioners and contractors compromise in favour of installability purposes	➢ Build a strong working relationship with people ➢ Detract from silo-working environment and initiate collaboration
16	Design coordination is a purposeful and goal-oriented activity which aims to coordinate all service design activities, processes and resources in building services engineering practices. ***What is your interpretation of design coordination?***	➢ Multidisciplinary awareness of respective design ➢ Over emphasis on BIM for coordination purposes ➢ Practitioners were more cognizant of coordination in the 2-D era ➢ Over-reliance on software technology to address shortcomings in design philosophy	➢ Regular multidisciplinary collaboration to ascertain the optimum design solution ➢ Each discipline to take responsibility for design coordination with clear tracking and communication therein	➢ In-house multidisciplinary processes and respective technical coordination ➢ Joint workshops to integrate coordinated design	➢ Design coordination is an multidisciplinary task with other disciplines – architectural on aesthetics, cost management on cost or contract, fire safety on escape strategy ➢ BSE ability to understand other discipline impact on their inherent design	➢ Multidisciplinary design team speaking the same language with the same goal in mind – technical coordination ➢ Technical coordination is a task that involves solely technical practitioners	➢ Mutual agreement with the design team from the project outset to understand the level of coordination required and achievable using the BIM model ➢ Caution in under-designing or over-designing a project is subject to client expectation and associated fee	➢ Continueous collaboration and clear communication between multidiscipline practitioners
17	It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40-50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. ***What is your professional experience thus far?***	➢ Limited BSE fee assigned to design stage ➢ Race-to-the-bottom; low fees compromise design ➢ Compromised design creates deficiencies at installation stage ➢ Practitioners lack of understanding of installation costs ➢ Shrewd mechanical and electrical contractors can *steer-a-ship* through the design gaps, thus secure additional costs	➢ Adequate time and resources allocated at design stage would minimize negative impact at construction stage ➢ The right people using BIM correctly with the right digital technology would minimize deficiencies at construction stage	➢ Project complexity dependent ➢ Correlation between lack of technical coordination and additional work required at construction stage including unwelcomed cost incurred to the client	➢ Inadequate resources allocated at design stage results in additional time spent at construction stage	➢ Unclear design brief with unrealistic deadlines instigates at design stage initiates deficiencies at construction stage ➢ Rushed-design leads to improper peer review ➢ High cost impact to rectify design deficiencies at construction stage	➢ A pressured BSE industry with work-winning on competitive fees with demanding clients potentially lead to dysfunction in practice ➢ Dynamic nature of the multidisciplinary BIM process at design and construction stages inevitably initiates dysfunction in BSE practice	➢ A measure-twice cut-once approach will mitigate deficiencies and dysfunction at construction stage
18	Design issues cannot be resolved by squeezing the design process, achieving milestones with less information or making explicit decisions to change the design process. ***Describe your experienced of this phenomenon?***	➢ A squeezed design process leads to inefficient design ➢ Technology impinges practitioners' true understanding of system design ➢ Greater design time leads mitigate shortcomings at installation stage, with improved relations with both the client and specialist contractors	➢ Early stakeholder / operator engagement at design stage reduces programme and cost impact at construction stage	➢ Resource allocation in the BSE design process is low compared to other disciplines ➢ Shorter programmes in modern construction projects is amplifying the resource issue ➢ Unbalanced resource allocation leads to inaccurate design ➢ Achieving milestones with competitive fees leads to poor coordinated design, which impacts the construction stage	➢ The right people with the technical know-how in understanding of scope of works and programme is imperative for successful project delivery ➢ Practitioner understanding of the greater design team variables will guide appropriate project deliverance	➢ Management seldom take cognizance of project variance, thus assuming similarities to past project delivery, which introduces risk in terms of design quality ➢ Project delivery in 2-D versus 3-d is often unrecognized by BSE management	➢ Inadequate design brief leads to design assumption, which introduces risk at design and construction stages ➢ Realisation of such risk is detrimental to practice	➢ Time constraint is perceived as the prominent problem in BSE practice ➢ Honest design delivery in a transparent manner yield greater efficiency and mitigates design errors or omissions

19	Information management is concerned with ensuring that the right information is available when required in the right format. ***Have you adapted a 'not reinventing the wheel' approach to your design?***	➢ Information request schedule by practitioners to the project team from the outset. ➢ Designing under perceived assumptions introduces risk ➢ Avoid being held accountable for subsequent project stages	➢ Cross reference to past projects to expedite the design process ➢ Lessons-learned on past projects is imperative to avoid similar design and installation issues arising ➢ Practitioner access to a shared unified file index	➢ In-house practice standards adopted to bespoke project requirements ➢ Initiate the right process to achieve the required quality by internal auditing and quality procedures at all project stages	➢ Getting-a-grip of practitioner design intent and how past project deliverables can be adopted on new projects to achieve efficiency during the design process ➢ Practitioner refrainment from reinventing-the-wheel	➢ The digital evolution is transforming BSE practice ➢ Delve into past project design data to expedite current project demands	➢ BSE design is evolving and practitioners need to take cognizance of every project separately ➢ Adopting previous design strategies could result in either over- or underdesign ➢ Design must reflect the client expectation for a respective fee	➢ Self-information management ➢ Caution being abreast with up-to-date building Standards
20	Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. ***What is your experience of being involved in a project where the building services engineer led and managed the programme?***	➢ BSE programme management is seldom priortised before architecture ➢ Design efficiencies by absolving BSE design into the overall programme ➢ Weaker design due to refined BSE programme input	➢ More technical projects tend to have BSE practitioners managing the programme, that is, data centres ➢ Better led by BSE practitioners have technical background as opposed to non-technical programme managers ➢ Positive outcome for a technical perspective, but less emphasis on cost and contractual issues	➢ Reliance on third-party input for design input and technical coordination ➢ Introducing risk at both design and construction stages when third-party data is not received in good time	➢ BSE practitioner bias to lead projects ➢ Underestimation of technical coordination of all design disciplines ➢ The art of smooth management	➢ Complex BSE biased projects demand greater BSE programme management ➢ Greater liaison with a higher number of technical stakeholders and clients	➢ Traditionally building programmes are managed by architects and structural engineers without BSE input, and adopting asumptions ➢ BSE is generally the last input in the BIM design process which potentially initiates dissonance between other disciplines by demanding reworks of their respective design	➢ N/A
21	Performance measurement provides a means of distinguishing between perception and fact at three levels; individual, project and organisational. A significant question for design performance measurement is whether improvements in design alone can lead to step changes in performance. ***How is performance measured in your practice?***	➢ BSE performance is measure by time, quality, collaboration and commitment to the project ➢ A project completed on-time with professional dissonance between practitioners is not a successful project ➢ Strive for constant improvements	➢ Professional goals for practitioners ➢ Financial performance ➢ Lack of technical competence performance metrics in BSE practice ➢ Operational metric of a building could potentially measure the technical performance of practice design	➢ Individual performance measured by management ➢ Resource allocation with programme adherence are measured from an in-house financial perspective (key performance indicator)	➢ A balanced cost and design quality are deemed the key performance indicators in BSE practice	➢ Performance is perceived as a measure of the quality of design deliverable ➢ Difficult to measure accurately due to fast pace BSE practice environment	➢ Practitioner performance is perceived as a measure by management of client / practitioner engagement, meeting client's expectations, interpersonal communications and punctuality	➢ Organisation devised practitioner performance measured annually by management ➢ Caution in large practices where practitioners feel undermanaged when performance indicators are released
22	Early engagement between the client and the technical design staff during the design process. ***In your professional experience, do you believe this communication correlates to the quality of design deliverable output?***	➢ Uninformed clients can lead to watered-down design or overdesign ➢ A well-informed client benefits the design scheme ➢ BSE practitioners to steer-the-course of the right level of design	➢ Practitioner understanding of client brief ➢ Client understanding of site design constraints ➢ Late engagement with the clients leads to a delayed design process, and in some instances, design issues are pushed-out to construction stage that incur additional cost and time delays.	➢ Correlation between early client engagement and the quality of design ➢ Design coordination is more efficient when practitioners understand the client's expectations	➢ Succinct client brief is essential from the project outset ➢ Client's vision of the project ➢ Practitioner realization of client's expectations ➢ Client understanding of design changes in terms of cost and programme	➢ Greater client-designer engagement yields improved design delivery ➢ Client expectations is delivered more efficiently through respective engagement	➢ Limited client-designer engagement at concept design stage initiates unclarity of design brief and client expectation	➢ Succint engagement with client will mitigate against abortive design work ➢ Understanding client expectation is paramount for successful delivery
23	The process of reflection in engineering design engineering is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. ***Do you consider yourself to be a reflective practitioner, that is, to reflect on your design so as to engage in a process of continuous learning.***	➢ Reflection in practice is imperative ➢ Smack-of-arrogance in suggesting any design cannot be improved ➢ Self-criticism	➢ Reflective practitioner by default ➢ Reflection promotes learning from experience and succinct decision-making	➢ Adopt lessons-learned from past projects to new projects in imperative for successful design delivery ➢ Adopt up-to-date digital technology to enhance design efficiency	➢ All BSE practitioners should be reflective in practice	➢ Continueous learning from past and current projects; the art of learning in-action and on-action ➢ Peer review is perceived as a reflective experience in practice	➢ Project pressure demand at design stage reducing time for self-reflection ➢ Peer review meetings are a tool to scrutinize design documentation, which initiates reflection amongst BSE practitioners ➢ Reflection is often perceived by practitioners as defending their inherent design strategy ➢ Discrepancies extrapolated from design are viewed by practitioners as reflective practice	➢ Acceptance of design shortcomings pave the way for practitioner learning ➢ Adoption of learning in-action and on-action is key to practitioner professional development

24	A successful building services engineering entity achieves client satisfaction, provides technically sound professional services and maintains a supportive and rewarding working environment for its staff. ***Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.***	➢ People respecting and supporting each other ➢ Individuals will not be *thrown-under-a-bus* ➢ A harmonious content environment leads to better design	➢ Multidisciplinary technical collaboration ➢ Multidisciplinary communication ➢ Client trust with technical ability ➢ Technical support with global reach	➢ The right people with the right technical know-how will enhance the design process and lead to client satisfaction ➢ The art of delegation with trust is key to a practice's success	➢ Technical approach to design in adherence to quality assurance and quality control stipulations ➢ Practitioner annual appraisal by management	➢ A combination of technical and practical (personable) oriented practitioners is perceived a well-balanced BSE team	➢ A strong team spirit advocates a supportive working environment to deliver a project successfully	➢ Total team transparency with formal informal communication between practitioners enables design productivity
25	The use of design decision-making tools in the propensity of power distribution, general and emergency lighting, lifts, lightning protection, heating, ventilation and daylight simulations, wind and solar energy, etc. may be useful for guidance. ***In your professional experience, how accurate are decision-making tools in your specialism?***	➢ Caution using design decision-making tools – practitioners can get software to give the right answer ➢ BSE practitioner to be cognizant of first-principle theory that underpins the software design.	➢ Caution with software packages ➢ Output is directly related to inputs by practitioners ➢ First principles understanding is essential when adopting prediction software	➢ Caution using digital software predictive modelling ➢ Practitioner manual check using first principles facilitates design accuracy	➢ Ascertaining the right input parameters at concept design stage will yield less-hassle at detail design stage ➢ Accurate design at design stage will reflected positively at installation stage	➢ Cautionary in adopting software tools without understanding the predicted outcome. ➢ Adopt a manual calculation approach initially and verify the predicted outcome using digital software ➢ A thorough understanding of all design variables by practitioners is paramount from the outset	➢ BSE practice advocated the use of digital tool to compliment design, but should only be used as a design guide ➢ Practitioner understanding of design fundamentals is key to a succinct digital design ➢ Practitioners often resort to external specialists to provide digital design representation	➢ Adopting digital software with gut-feeling first principles can deliver rational design more effectively
26	Building Information Modelling (BIM) is not just a fancy 3-d model. It is about moving away from traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. ***Describe your challenges during the transition from 2-D to 3-D modelling during the design process.***	➢ Not all design partners are equipped with this digital technology ➢ Knowledge base is lacking amongst the design team	➢ Time and cost challenges to 3-D adoption ➢ 2-D design coordination was allocated to contractors during installation stage ➢ Practitioners cannot hide behind 3-D design ➢ Consultant fees do not reflect the transition from 2-D to 3-D design	➢ BIM adoption in its infancy in BSE practice ➢ Challenge for senior practitioners ➢ Knowledge gap between engineers and technologists ➢ Technologist need to understand the design intent ➢ Senior management to acknowledge the 2-D/3-D learning gap to be bridged	➢ BIM adoption is challenging when not all discipline practitioners have the same technical knowledge or readiness ➢ Irish contractors tender on 2-D documentation with 3-D for information purposes ➢ Challenge for junior practitioners who are BIM savvy, but underestimate the precise 2-D design content to be communicated for accurate pricing ➢ Continuous BIM changes by other disciplines is difficult to manage with stringent tracking to avoid abortive rework	➢ BIM enhances the visuality of the design intent ➢ Demands greater technical skills and creativity by practitioners to adopt compared to 2-D traditional design	➢ BSE management is perceived as underskilled in delivering projects in 3-D BIM ➢ Misunderstanding by management on resource allocation associated with BIM delivery leading to inadequate fee allocation	➢ Junior practitioners perceive 3-D BIM process as the only feasible design tool to deliver a complete project successfully and more accurately
27	MagiCAD offers integral BIM 3-d software for building services engineering design. It is a powerful enhancement tool developed to save time with more user-friendly, flexible, intelligent, and parametrical user environment. ***How has your experience been thus far?***	➢ N/A	➢ Limited knowledge of in-built design software ➢ Peer review of design may be problematic, and reviewers are not familiar with the software	➢ Time consuming to adopt MagiCAD due to dependency of procuring equipment details from third-parties ➢ Facilitate asset and information management ➢ Planned adoption would save significant time at design stage	➢ Procuring accurate equipment data from third parties is a challenge to maintain control over project design deliverables ➢ Caution with possible compromising of product optioneering ➢ Improves productivity at design stage and endorses BIM adoption	➢ Intelligent design tool to enhance proficiency the BSE design process ➢ Requires practitioners to upskill	➢ N/A	➢ Effective tool when applied in tandem with BIM provides accurate design outputs ➢ Upskilling required to reap its full benefits
28	Inefficiencies in engineering practice at design stage are noted as follows; lack of design coordination between disciplines leading to installability issues, poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision-making, and poor design quality As the design process is found to be a major source of problems at construction stage, even to the extent of undermining systematic management, the following deficiencies were identified: inferior quality of installation, time delay of installation, increased cost of installation, and redesign.	➢ Constant learning ➢ Better people doing better things in a better way ➢ Contractors will always find problems at installation stage ➢ Mitigate on-site problems by improved management, knowledge, experience, understanding, coordination, right questions to the right people at the right time, right fee to cost effectively meet the programme.	➢ Poor design quality ➢ Mitigation measures include a stringent quality assurance procedure at all project life stages ➢ Awareness by practitioners that their respective design correlates to the quality of installation at construction stage	➢ Mitigating all potential problem at construction stage is unrealistic ➢ A well-oiled practice will always face an element of redesign ➢ Applying lessons learned for past projects can mitigate redesign at construction stage	➢ Lack of coordination and communication is generally evident on most projects, which cause deficiencies at construction stage, including programme delay, additional cost and redesign in BSE practice ➢ Miscommunication between design disciplines is deemed to instigate requests for information, redesign, and researching appropriate problem-solving methods	➢ A competitive talent acquisition in Ireland incurs regular practitioner movement from practice to practice ➢ Challenging to retain practice tacit knowledge, which can result in design efficiency and subsequent dysfunction in practice	➢ Periodic review of successful and unsuccessful projects by BSE management and practitioners to access decision-making and fee spend at design stage ➢ Tendancy by management not to communicate overspend to practitioners ➢ BSE teams tend not to celebrate successful projects due to time and work demands	➢ Additional time allocated to the design stage to ensure accurate design, thus meeting stringent deadlines ➢ Peer reviews alleviate re-design

	As a direct consequence of these deficiencies, the impact in design consultancy practices is significant. The primary dysfunctions relate to: professional dissonance, poor design quality, redesign programme, and redesign cost. ***How has your organisation dealt with practice dysfunction?***							

Appendix 17 Case study interview analysis (Internal – PCC consultants)

NR	INTERVIEW QUESTION	PARTICIPANT 1 *PCC Practice Lead*	PARTICIPANT 2 *Cost Control Lead*	PARTICIPANT 3 *Project Cost Controller*
1	***How would you best describe the building service engineering design process?***	➢ PCC perceived no requirement for their discipline to understand the BSE design process ➢ Traditionally PCC assumes minimal involvement during a muiltidisciplinary design process ➢ Role of assessing cost of completed design	➢ Traditional design process led by the architectural team involving multidisciplinary coordination	➢ Design process is attributed to the mechanical and electrical element of the built environment ➢ Concept design is based on client's expectations ➢ Detailed design is based on input from the end-user / facility management and stakeholders with budget and level of quality in mind ➢ Legislative drivers in the context of sustainability performance, safety and building regulations
2	Ineffective design management results in extended design timescales and the production of poor-quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. ***Explain how your professional experience relates to this trend?***	➢ Incomplete design at tender stage initiated programme and cost impact at construction stage	➢ Project dependant; public or private sector ➢ Public sector comprehensive design in adherence to capital framework guidelines ➢ Adequate programme to produce accurate tender documentation for costing ➢ Private sectors tender documentation may contain provisional sums for incomplete system design	➢ Poor design performance is instigated from both the client and BSE management sides ➢ Accurate design brief informs adequate recourses to be allocated in a supportive multidisciplinary network ➢ Adherence to lesson-learned on similar type projects to avoid future mistakes
3	What was once deemed the province of a craftsman now demands the services of a body of highly educated and specialist trained professional engineers. However, it is inferred that academia alone does not form a solid foundation for engineering graduates in the building services engineering. ***Has the Irish engineering education system adequately prepared you for practice?*** ***Can you identify potential improvements in academia to produce better prepared graduates?***	➢ Traditionally designers had a craftsman's background; commencing with practical experience followed by academia ➢ Modern BSE discipline training has evolved with academia followed by practical experience	➢ Academia prepare practitioners to an extent, but lacks hand-on practical experience ➢ Trade experience at undergraduate level would enhance practitioner knowledge	➢ Academia is an important stepping stone into the professional world of design ➢ Graduates must possess an interest in their future career and show some desire to learn from taught programmes ➢ University programmes to provide industry standard software ➢ Work placement for real exposure to office dynamics, teamworking and management
4	Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead whilst only 15% is due to your technical knowledge. ***Explain how this statement applies to your engineering team?***	➢ Personality, interpersonal skills, negotiating attributes with fundamental design principles are imperative to business success ➢ Technical incompetence triggers additional project costs	➢ Interpersonal communication skills and negotiating attributes are imperative to business success in tandem with technical know-how ➢ Mis-use of technology initiates inefficiency in practice	➢ Strong interpersonal skills and openness to communicate favours practitioner success ➢ A combination of technical and communicative skills yields the best project outcome
5	As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. ***How do you foresee bridging this gap?***	➢ Assumption that practitioners will naturally move to a managerial role ➢ Practitioners should be conscious of their career path with the provision of training and mentorship from management	➢ Experiental learning and learning-by-example are key to bridging the gap from practitioner to manager	➢ Self-discipline with career progression in mind ➢ Taking on more responsibility and transgress from practitioner to manager ➢ Upskilling for the inherent transition
6	Engineering is increasingly being recognised as a technical and social process. Indeed, it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between design and construction professionals, hence the need to improve the technical/social dualism. ***What are your thoughts on this statement?***	➢ BSE practitioners and specialists perceived as huddling-up to work out the practical aspect of installability at construction stage ➢ BSE practitioners are more collaborative with contractors than PCC at construction stage	➢ BSE practitioners understand the design concept, but the road to installation is of less concern ➢ Contractors are more concerned with the road journey and installability at the end of the road	➢ BSE practitioners affiliation with design and ownership ➢ BSE specialist contractor is financially driven

7	Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy, but from the managerial complexity. ***What is your experience?***	➢ Degree of complexity in delivering BSE projects due to technical intracity ➢ Early client engagement with an efficient engineering manager is perceived to simplify the BSE design process	➢ Technical savviness to deliver a comprehensive coordinated design,thus minimizing issues at construction stage	➢ Experienced BSE management to resolve technical difficulties ➢ Ability to foresee shortcomings whilst interacting with other disciplines
8	It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. ***Do you agree with this statement? How do you envisage such communication problems may be improved?***	➢ Inherent waste where people work under direction ➢ Lack of managerial and communication skills initiate reword with cost implications	➢ How management communicate tasks to practitioners from client briefings is imperative from the project outset to minimize waste in practice ➢ Client management to ensure the design brief is succinctly captured prior to design will avoid redesign ➢ Clear communication with the client with regard to project deliverable	➢ Management attribute dependency ➢ Effective management yields higher utilization rates and efficient working environment ➢ Good utilization promotes practice strategy with work-wins in the right market
9	The building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management during construction. ***What is your experience?***	➢ Generally undermining management is rare in construction practice	➢ Inadequate data gathering at design stage can impose issue downstream resulting in practice dysfunction	➢ Technology driven buildings require high technical capability ➢ Prompt client briefing mitigates double-handling multidisciplinary design
10	Dissonance between designs in an multidisciplinary practice is often brushed-under-the-carpet at design stage. ***How do you relate to this phenomenon?***	➢ Close collaboration in Irish design teams is evident ➢ Resolution to shortcomings are resolved prior to instigating a major problem	➢ Building a strong relationship with other team disciplines ➢ Refrain from hiding behind technology whilst attempting to resolve issued	➢ Potential relaxed approach in single multidisciplinary practices ➢ Sub-conscious complacency in standards compared to partnering with external disciplines
11	Successful building services engineering design management needs management ; excellent interpersonal skills are imperative. ***What is your understanding of management in a building services engineering practice?***	➢ Management demands an understanding of practitioner technical know-how	➢ Allocating the right practitioners with the technical know-how, trade experience to foresee and effectively address problematic issues in a concise manner ➢ Client management with excellent communication and interpersonal skills	➢ Effective internal (practitioners) and external (client) management ➢ Adequate skillset with focus on work-wins and projected workload
12	Due to commercial and time constraints, practices are often unable to meet learning targets with formal training programs, and as such resort to informal training programs. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is an organisation skilled at creating, acquiring, and interpreting, transferring and retaining knowledge. ***How does your practice learn at a rate that gives you a sustainable professional advantage?***	➢ Recruting the right people with the right skillset is fundamental to business ➢ Large scale organisations have the capacity to invest and provide further cutting-edge training to practitioners	➢ Adequate formal training provided in large scale practices	➢ Management to facilitate practitioner diverse training in technical and business practice acumen ➢ Practitioner responsibility to engage with professional institutes
13	The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage, and consequently, dysfunction in practice. ***What is your experience during the project lifecycle?***	➢ Lessons learned from past projects should be adopted to new projects ➢ Practitioners to be made aware of their contribution to inefficiencies and address in subsequent projects	➢ The design process demands a collaborative working environment in order to produce a suite of design documentation ➢ A non-collaborative environment would lead to failed projects ➢ Programme pressure kills the design process disallowing practitioners to be effectively collaborative	➢ Individual disciplines with own agenda – programme and cost ➢ Long term lifecycle costing is generally not at the forefront, which would promote a quality building over the project lifespan
14	The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos which provides further challenges. ***Has your team experienced this phenomenon, and what are your concerns for future-multidisciplinary design?***	➢ A collaborative team approach is vital where multispecialisms work on the same project ➢ Integrating specialism into a collaborative team	➢ Performance specification of BSE system can instigate challenges and lead to technical coordination issues at installation stage	➢ Specialism improve the quality of building design ➢ Digital technology has positively impacted the design process ➢ Technical coordination is more challenging

15	Technical coordination in the context of building services engineering means working with and influencing other members of the design team so they conscientiously perform necessary work in accordance with a mutually agreed schedule. ***In your professional experience, please articulate how coordinating technical work of other people by gaining their willing cooperation is a major aspect of engineering practice.***	➢ The adoption of digital technology is paving the way for an improved collaborative working environment	➢ Articulation, communication, cooperating amongst practitioners produced a well technically coordinated design	➢ An effective manager with technical know-how and transparent communication skills are key attributes of BSE management ➢ Failure to possess these attributes will inevitably result in additional cost post contract signing ➢ Treat all disciplines with equal importance results in a quality product
16	Design coordination is a purposeful and goal-oriented activity which aims to coordinate all service design activities, processes and resources in building services engineering practices. ***What is your interpretation of design coordination?***	➢ Technical coordination yields a solid cost with intended aesthetics	➢ A coordinated multidisciplinary design sings-in-harmony	➢ Design coordination entails good communication, mindfulness of programme, awareness of workload and associated timescales, setting actions ➢ knowing client deliverables expectations and good technical knowledge in all disciplines
17	It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40-50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. ***What is your professional experience thus far?***	➢ Agreement that problems initiated at design stage incur deficiencies at construction stage	➢ Incomplete design on private sector projects is more problematic at construction stage due to provisional sums; onus on practitioners to complete technical coordination at installation stage, which incurs both additional cost and resourcing ➢ Public sector projects demand fully coordinated design prior to tender	➢ Design gaps result in costs to the client ➢ Awareness of contractual claims and commercial strategy from contractor will negate variations ➢ Economic climate may dictate commercial appetite; design deficiency is subjective ➢ Additional time spent rectifying changes and agreeing costs for gaps in design
18	Design issues cannot be resolved by squeezing the design process, achieving milestones with less information or making explicit decisions to change the design process. ***Describe your experienced of this phenomenon?***	➢ From an experiental perspective, squeezing the design process has a detrimental affect at construction stage	➢ Shortening the design process never works ➢ Value engineering may favour the design process in terms of programme implication ➢ Direct correlation between squeezing the design process and increasing costs at construction stage ➢	➢ Achieving design quality is important ➢ Allocating appropriate time to develop a design ➢ Injecting more time and cost into the design stage may nullify expensive contractual claims
19	Information management is concerned with ensuring that the right information is available when required in the right format. ***Have you adapted a 'not reinventing the wheel' approach to your design?***	➢ Standard libraries containing reference documents and solutions are key to efficient delivery	➢ Electronic information management for ease of access	➢ Build a database of information and develop it ➢ Use best practice designs and adapting any deficient design through continual correction and modifications
20	Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. ***What is your experience of being involved in a project where the building services engineer led and managed the programme?***	➢ Programme management should be delivered by the discipline project lead	➢ Declined to respond	➢ Declined to respond
21	Performance measurement provides a means of distinguishing between perception and fact at three levels; individual, project and organisational. A significant question for design performance measurement is whether improvements in design alone can lead to step changes in performance. ***How is performance measured in your practice?***	➢ Individual performance is conducted by performance management and reward process ➢ Structured annual process where practitioners set goals and management apply a rating ➢ Project and organisational success is rated by financial metrics	➢ Performance measured in the context of financial and success delivery to clients	➢ Consultancy industry is measured on commercial acumen ➢ Budget and cost planning accuracy ➢ Adding value to the client through identification of savings rebuffing claims in accordance with good contract administration.
22	Early engagement between the client and the technical design staff during the design process. ***In your professional experience, do you believe this communication correlates to the quality of design deliverable output?***	➢ Early client engagement lays the foundation stone for the remaining stages of the project delivery	➢ Early engagement with clients is crucial to developing a clear project brief and delivering a successful project ➢ The sooner the practitioner-client bridge is built and communicative flow is established the higher the efficiency of the design process ➢ Accurate intepretation leads to successful delivery	➢ Clear communication provides accurate client representation of design ➢ Early engagement brings a healthy interface between an informed and equipped client for design success

23	The process of reflection in engineering design engineering is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. ***Do you consider yourself to be a reflective practitioner, that is, to reflect on your design so as to engage in a process of continuous learning.***	➢ Declined to respond	➢ Lessons-learned interpreted as reflection ➢ Avoiding a copy-and-paste approach will minimize inaccurate design	➢ Reflection attributes to self-development and professional competence
24	A successful building services engineering entity achieves client satisfaction, provides technically sound professional services and maintains a supportive and rewarding working environment for its staff. ***Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.***	➢ Principle focus to deliver a professional service ➢ Create a supportive network within the practice ➢ Upskill practitioners in state-of-the-art technology which offers career progression	➢ Allocating practitioners to project types that they have been previously successful intimates satisfaction	➢ Technical competence and familiarity with construction methods and building types ➢ Good relationships in an office environment will overcome issues such as lack of time, lack of knowledge and lack of resource to complete a task successfully ➢ Knowledge and experience creates a successful working environments.
25	The use of design decision-making tools in the propensity of power distribution, general and emergency lighting, lifts, lightning protection, heating, ventilation and daylight simulations, wind and solar energy, etc. may be useful for guidance. ***In your professional experience, how accurate are decision-making tools in your specialism?***	➢ N/A	➢ N/A	➢ N/A
26	Building Information Modelling (BIM) is not just a fancy 3-d model. It is about moving away from traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. ***Describe your challenges during the transition from 2-D to 3-D modelling during the design process.***	➢ Challenging to persuade the Irish construction industry to invest in new digital technology ➢ Client do not recognize the value of BIM and industry research ➢ Limited incentives to adopt new digital technolog	➢ Ongoing reliance on 2-D documentation to cost project design ➢ Upskilling required to cost from a 3-D BIM model	➢ Operates on what BSE practitioners have produced ➢ Production of 3-D models has aided cost consultants as they provide visual guidance on intricate designs, used within cost measurement software ➢ BIM is a developing paradigm, weaknesses still exist
27	MagiCAD offers integral BIM 3-d software for building services engineering design. It is a powerful enhancement tool developed to save time with more user-friendly, flexible, intelligent, and parametrical user environment. ***How has your experience been thus far?***	➢ N/A	➢ N/A	➢ N/A
28	Inefficiencies in engineering practice at design stage are noted as follows; lack of design coordination between disciplines leading to installability issues, poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision-making, and poor design quality As the design process is found to be a major source of problems at construction stage, even to the extent of undermining systematic management, the following deficiencies were identified: inferior quality of installation, time delay of installation, increased cost of installation, and redesign. As a direct consequence of these deficiencies, the impact in design consultancy practices is significant. The primary dysfunctions relate to: professional dissonance, poor design quality, redesign programme, and redesign cost. ***How has your organisation dealt with practice dysfunction?***	➢ Inefficiencies are addressed by detailed design reviews ➢ Peer reviews are intended to prevent repeat shortcomings and project failures ➢ Introduction of healthy program from the project outset to mitigate practice dysfunction	➢ Avoid projects where project brief is poor which would inevitably lead to poor design, coordination and communication ➢ Reasonably defined brief also creates practice dysfunction ➢ Ascertaining a clear brief to cascade to practitioners is imperative for successful project delivery	➢ To protect the business, quality management is introduced ➢ Checking procedures are now used regularly ➢ To ensure that efficient working and uniformity and consistency of service is there, libraries of information are set up ➢ Guidance documentation and templates are used as the basis for the completion of tasks ➢ Regular communication to the wider working team in Ireland means that teams can benefit from past experience on certain project types ➢ Best practice procedures are identified, and a formal and informal lessons learnt exercise is used.

Appendix 18 *Case study interview analysis (External - SC professionals)*

NR	INTERVIEW QUESTION	PARTICIPANT 1 *BSE Contracting Lead*	PARTICIPANT 2 *Electrical Contracting Lead (Technical)*	PARTICIPANT 3 *Mechanical Contracting Lead (Technical)*	PARTICIPANT 4 *Electrical Contracting (Cost Control)*	PARTICIPANT 5 *Mechanical Contracting (Cost Control)*
1	***How would you best describe the building service engineering design process?***	➢ Collaborative process within a multi-disciplinary team and with external disciplines from project concept to completion resulting in a good quality building	➢ Inexperienced BSE consultants produce vague design, which impact the remaining project stages	➢ The design process is ever-evolving	➢ Preparation of a partically coordinated suite of design documentation for costing	➢ Early engagement with contractor to vet design, initiate cost surety by protecting against potential future claims
2	Ineffective design management results in extended design timescales and the production of poor-quality tender documentation. Any unresolved design issues have to be resolved at some point in order for the building services installation to be successful. ***Explain how your professional experience relates to this trend?***	➢ Unresolved issues at tender stage result in many delays and costs ➢ Poor design coordination as opposed to poor design ➢ Refurbishment projects are more susceptible to this phenomema, as opposed to new builds	➢ Incomplete design leads to misinterpretation, with a subsequent battle at installation stage ➢ Early contractor involvement to ascertain installability	➢ Engineering and construction are intrinsically linked ➢ Delay in the design results in the delayed procurement of equipment leading to delayed installation, testing & commissioning	➢ Multidisciplinary design teams under pressure to complete tender design package, which leads to limited technical coordination that generates costly problems at construction stage	➢ Complex projects demands contractor early engagement with the design team ➢ In-house contractor design team to support clients' project team
3	What was once deemed the province of a craftsman now demands the services of a body of highly educated and specialist trained professional engineers. However, it is inferred that academia alone does not form a solid foundation for engineering graduates in the building services engineering. ***Has the Irish engineering education system adequately prepared you for practice?*** ***Can you identify potential improvements in academia to produce better prepared graduates?***	➢ Irish education system was not adequately prepares graduates for engineering practice (2007) from a practical perspective ➢ Technical theory and calculations at undergrade level has underpinned successful engineering practice in subsequent years ➢ Universities appear to be more keen on rolling out new technology software as opposed to be lead by industry best practice; this philosophy could be improved	➢ Evolution of craftsmen to professionals ➢ Efficient practitioners initiate training as apprentices; invaluable practical experience	➢ Site experience enhances ones design ability ➢ Work placement scheme to help facilitate this to form part of a final year course requirement	➢ 80% academia and 20% practical experience ➢ Apprenticeships facilitate a solid background for construction professionalism	➢ Internal graduate training programme to guide practitioners on their career path
4	Recent research shows that 85% of financial success is due to your personality and your ability to communicate, negotiate and lead whilst only 15% is due to your technical knowledge. ***Explain how this statement applies to your engineering team?***	➢ 50:50 in the building services engineering practice ➢ As one transitions from engineer to management, the percentage for personality, communication and management increases	➢ Practitioner interpersonable ability to communicate and negotiate effectively	➢ Open positive form of communication ➢ Removal of the traditional blame-game and replaced with a team-resolution approach	➢ BSE practitioners dependence on foremen to provide direction on system installability	➢ Create constructability reports from an operational, scheduling and commercial perspective with roles and responsibilities ➢ Financial success falls on the back of operational and quality of delivery ➢ Technical knowledge and early engagement with the design team is imperative for successful project delivery
5	As a building services engineering professional, there is limited or no guidance from the transition from building services engineer to design manager. ***How do you foresee bridging this gap?***	➢ No formal training from design engineer to design manager ➢ Not something one can train directly; it comes with adequate engineering design experience	➢ Practitioner transition to management demands technical know-how with experience and a strong communication attribute	➢ Project exposure assists with the technical knowledge ➢ Social element teased out via company in-house training programs	➢ Multidisciplinary training programmes to assist with smooth transition	➢ Process mapping with roles and responsibilities identify practitioner and management functional tasks

6	Engineering is increasingly being recognised as a technical and social process. Indeed, it has been articulated that designers have a conceptual mind while contractors have a concrete mind. This belief alone suggests dissonance between design and construction professionals, hence the need to improve the technical/social dualism. ***What are your thoughts on this statement?***	➢ Understanding people's capabilities ➢ Understanding the Irish construction industry ➢ Not to throw colleagues in the deep end too soon ➢ Facilitae confidence building in teams ➢ Invest time in mentorship	➢ An effective constructive model would include contractor engagement during the design process to bridge the gap between practitioner knowledge and contractor installability	➢ Important role of MEP coordinator who mediates between the designer and installer ➢ Focus on communication abilities in addition to technical competence when recruiting ➢ Communication needs to have as much emphasis as any other corner stone topic in an engineering course	➢ Generally, designers are office based whereas contractors are site based, which leads to miscommunication and delays in problem-solving	➢ Working as a team with defined roles ➢ Business collaboration between team members to ascertain commercial validation
7	Design is a difficult process to manage and needs effective planning and control to minimise the effects of complexity and uncertainty at construction stage. Indeed, the difficulty in designing engineering projects does not arise from technical intricacy, but from the managerial complexity. ***What is your experience?***	➢ Develop a risk register from the outset ➢ Continual risk management workshops ➢ Reduce risk to an acceptable level	➢ Multidisciplinary communication management deploying a succinct collaborative working environment approach to design	➢ Projects overseen by time efficient decision makers reduces issues ➢ A single decision-maker can lead to delays	➢ Transparent communication between the design and construction teams	➢ Design deliverables with close out dates
8	It is estimated that 80% of waste in most organisations is due to management, particularly how managers ask engineers to carry out tasks. ***Do you agree with this statement? How do you envisage such communication problems may be improved?***	➢ Inefficiencies are normally down to out-dated industry practice ➢ Engineering design managers set out the design criteria, but the methods used to solve these technical issues is normally the design engineers initiative	➢ Waste initiates in BSE design practice and affects all subsequent project stages ➢ Regular communication to negate misinterpretation	➢ Managers should request early feedback from discipline practitioners to ensure that the message was received and interpreted correctly ➢ Based on its complexity, this could be in the form of a 30/60/90% feedback on the task	➢ Managers pass down their *dirty work* to overworked practitioners with limited time to resolve resulting in further error and waste	➢ Practitioner roles are clearly defined; engineers know their expectations on a project by project basis
9	The building services engineering design process is found to be a major source of problems for the subsequent project phases, even to the extent of undermining systematic management during construction. ***What is your experience?***	➢ Total dependence on software ➢ Consider validation through manual calculation	➢ Quality of design and interaction between the design and construction teams is imperative to deliver a successful project ➢ Traditional site liaison to solve installability issues is replace with an administrative request for information protocol	➢ Not necessarily a negative aspect ➢ As projects progress, the nature of the project and how it is achieved requires review and amendments if required	➢ Silo working environment tends to promote kicking the can down the road when design problem are evident	➢ In-house engineers to review vet the proposed design to identify gaps and minimize future risk
10	Dissonance between designs in an multidisciplinary practice is often brushed-under-the-carpet at design stage. ***How do you relate to this phenomenon?***	➢ Engineers work in silos albeit cognisant of interface requirements between other discipline design, sometimes this interface is not documented at design stage ➢ Dependance on 'good contactors' to rectify the interface informally at construction stage ➢ Such disparities generally instigate site visits	➢ Perception that one multidisciplinary practice is fully coordinated is not always the case unless effect management is instilled	➢ People by nature focus on their tasks, thus tend to overlook the bigger picture ➢ Greater focus required on project delivery as a whole, as opposed to their respective disciplines	➢ Declined to respond	➢ Understanding the clients' expectation ➢ Early engagement with the client and design team to ascertain the performance requirements, programme to define a succinct responsibility matrix
11	Successful building services engineering design management needs management ; excellent interpersonal skills are imperative. ***What is your understanding of management in a building services engineering practice?***	➢ High level of technical ability ➢ Approachable to discuss technical queries ➢ Non-blame attitude and culture ➢ Understanding of time contraints to complete design	➢ Management is the ability to bring a team together by involving them in the initial process to express their innovative ideas ➢ Management to make people feel part of the team	➢ Ability to say *No* ➢ Endeavor to meet challenging deadlines ➢ Not compromise on quality ➢ Effective communicator, motivator and negotiator	➢ Interaction and communication with the overall project team ➢ Management by example	➢ Lead the overall plan of work for the project to ensure activities are addressed
12	Due to commercial and time constraints, practices are often unable to meet learning targets with formal training programs, and as such resort to informal training programs. The act of learning in a professional practice is directly related to how managers can stimulate learning. A learning practice is an organisation skilled at creating, acquiring, and interpreting, transferring and retaining knowledge. ***How does your practice learn at a rate that gives you a sustainable professional advantage?***	➢ Insufficient time for adequate formal training due to project time demands ➢ Aspiration to implement new technologies for design, but new time constraints limit the time required to research the feasibility of such technologies	➢ Graduate training programme on both engineering practice and professional development with targeted remuneration package	➢ Recognition is a driver within thriving practices ➢ Competency assurance mentor and coordinator ➢ high value on annual continual professional development and chartership status for engineers	➢ Knowledge sharing of lessons-learned on past projects to practitioners and the project team ➢ Adoption of digital tools to monitor and disseminate lesson-learned to the project team	➢ Lessons-learned approach from past projects to future projects ➢ Practitioner learning by example from engineering manager

13	The current building engineering design process is typically serial and non-collaborative. Inefficiencies at design stage lead to deficiencies at construction stage, and consequently, dysfunction in practice. ***What is your experience during the project lifecycle?***	➢ Inefficiencies are normally down to out-dated industry practice ➢ Engineering design managers set out the design criteria, but the methods used to solve these technical issues is normally the design engineers initiative	➢ Issues come to light at installation stage when costs are incurred to rectify the situation ➢ Appropriate practical experience, can reduce this risk ➢ Easier to fix a problem on paper initially than nearing the end of the installation	➢ Irish trend of aggressive programme and tight margins force progress over quality, which yields an overspend in time and money ➢ Practices try to save on the front-end instead of resourcing efficiently from the start	➢ Shortcomings in design are recognized by installation contractors at construction stage ➢ Blame is normally directed to the respective discipline	➢ Project team collaboration ➢ design overruns means compressed construction
14	The increasing number of specialisms in the building services engineering design process results in technical staff tendencies to work in silos which provides further challenges. ***Has your team experienced this phenomenon, and what are your concerns for future-multidisciplinary design?***	➢ The introduction of specialisms such as building information modelling (BIM), thermal modelling (TM) and computational fluid dynamics (CFD) has paved the way for ‘silo’ working environment; ‘one-for-all’ building services engineer is not practical	➢ Specialisms’ ability to communicate in a multidisciplinary team setting is limited ➢ Digital technology has the ability to improve this general trait	➢ An open form of communication culture to reduce barriers created by people working in isolation	➢ bespoke buildings with specific client demands benefit from dedicated specialisms	➢ People with clear understanding their role responsibilities and deliverables
15	Technical coordination in the context of building services engineering means working with and influencing other members of the design team so they conscientiously perform necessary work in accordance with a mutually agreed schedule. ***In your professional experience, please articulate how coordinating technical work of other people by gaining their willing cooperation is a major aspect of engineering practice.***	➢ Mutual understanding of design intent between disciplines is paramount to a successful project ➢ Design intent changes should be communicated to design engineers with relevant reasoned explanations	➢ Accurate technical coordination can facilitate minimalistic design for appropriate clients	➢ Maintaining a respectful work environment ➢ One which recognizes that a healthy work-life balance is required ➢ Developing a close-knit team encourages an *all for one and one for all attitude*, which benefits project team when faced with looming deadlines	➢ Strong team communication promotes accurate technical coordination	➢ Align design deliverables with overall programme ➢ Manage and coordinate peoples’ expectation and deliverabes
16	Design coordination is a purposeful and goal-oriented activity which aims to coordinate all service design activities, processes and resources in building services engineering practices. ***What is your interpretation of design coordination?***	➢ Marry individual design on a continual basis into one whole design in order to deliver a successful project	➢ Multidisciplinary team responsibility to coordinate design to minimize waste-space ➢ Contractor to facilitate further coordination at installation stage	➢ Overview to bring a client's vision from concept to completion	➢ Design coordination intricities arise when uncomplete design is recognized at construction stage ➢ Client instigated changes at construction stage can equally overlook the true impact of the respective change	➢ Design and coordinate through BIM ➢ Off-site fabrication
17	It is recognised that 75% of the problems encountered at construction stage are generated at the design stage, but their impact is rarely understood in terms of cost and programme in design practices. It is estimated that an additional 40-50% of the total work hours of a project may be required to rectify such deficiencies at construction stage. ***What is your professional experience thus far?***	➢ I would agree completely with this statement. Poor design documentation leads to disruption and carniege at construction stage.	➢ Percentage of time or cost to rectify design shortcoming at design stage is quantified in hours, but to rectify the same shortcoming at construction stage takes approximately *tenfold* the time	➢ Early contractor appointed promotes time for joint-review and collaboration ➢ Allowing the contractor to review and provide input into the design ensures certainity in pricing	➢ Early design-construction team interaction minimizes potential problems and maximises efficiency in solving such issues	➢ Pre-construction hours to resolve design deficiencies ➢ Constructability strategy developed at the design review stage
18	Design issues cannot be resolved by squeezing the design process, achieving milestones with less information or making explicit decisions to change the design process. ***Describe your experienced of this phenomenon?***	➢ Redesigned a 8,000m² office building as a result of been ‘pushed’ to unrealistic tender date ➢ Insufficient coordination with other design team disciplines resulting in signigicant delays at construction stage	➢ Rushing the design process is part and parcel of construction ➢ Inadequate time to review design at stages results in limited period to amend the respective design	➢ Placing progress in front of quality ultimately results in additional time and cost at the back end of a project ➢ Time increases will allow for design development but the completion date remain the same, resulting in a squeezed install or commissioning program	➢ In the real-world, programme is pressure that leads to inherent and subsequent problems	➢ Attempts to address design gaps at pre-construction stage are generally addressed by experienced professionals
19	Information management is concerned with ensuring that the right information is available when required in the right format. ***Have you adapted a ‘not reinventing the wheel’ approach to your design?***	➢ 60%-70% of information from previous design work has been adopted for new projects ➢ Up-to-date industry standards and specifications must be managed and easily accessible for all project design	➢ Early engagement on a project can ascertain forseeable shortcomings in design ➢ Adopt a logical approach to rectify such issues	➢ Ensuring the right information is provided to the right person and understood, but limit information overload	➢ Refrain from over-complicating matters ➢ Ad-hod design changes during site-walks are difficult to manage by absentees	➢ The key is lessons-learned - *don’t lose-out where one lost-out before* ➢ Learning and implementing best practice

20	Programme management of projects is concerned with ensuring that activities are complete to achieve project objectives. ***What is your experience of being involved in a project where the building services engineer led and managed the programme?***	➢ 60%-70% of information from previous design work has been adopted for new projects ➢ Up-to-date industry standards and specifications must be managed and easily accessible for all project design	➢ BSE managing a programme is an effective approach with focus on technical coordination rather than traditional aesthetics	➢ BSE management favourable on high-technical projects	➢ Generally projects are rarely managed by the BSE discipline lead	➢ Project managers to lead the programme, as opposed to engineering practitioners ➢ Engineering lead feeds back to the project manager
21	Performance measurement provides a means of distinguishing between perception and fact at three levels; individual, project and organisational. A significant question for design performance measurement is whether improvements in design alone can lead to step changes in performance. ***How is performance measured in your practice?***	➢ No experience of performance management	➢ Contractor performance is measured from acquiring the design, coordinated to produce the end product within programme within budget to the client's satisfaction	➢ Annual key performance indicators outlay identify level of competenc and career progression	➢ Performance is measured b completing the project on time, within budget, quality of installation, health and safety record, project complexity	➢ individual basis - measured on KPIs ➢ project level - measured on roles and responsibilities being delivered which maps up the KPIs, thus mapping the overall business strategy
22	Early engagement between the client and the technical design staff during the design process. ***In your professional experience, do you believe this communication correlates to the quality of design deliverable output?***	➢ Dependant on client's technical knowledge ➢ A client with technical know-how can hinder the quality of design by demanding 'their way of doing things ➢ A client with a non technical background gives an engineer freedom to develop their individual design subject to stipulated design parameters	➢ Through BIM adoption, aligning the client with the design team at an early stage will visualize the end-product and facilitate the development of a clear brief	➢ Yields a thorough detailed final design ➢ Gives the contractor a degree of comfort knowing that all items have been priced	➢ Early engagement with client is imperative ➢ Design stage – I want this, that and the other ➢ Construction stage – I don't want this, that and the other	➢ Design weakness needs to be addressed from the project outset to negate reputational, commercial or cost damages
23	The process of reflection in engineering design engineering is often inspired by discrepancies in existing knowledge, skills and indeed people's attitudes. ***Do you consider yourself to be a reflective practitioner, that is, to reflect on your design so as to engage in a process of continuous learning.***	➢ Building services engineering is about bringing buildings to life by often meeting technical performance requirement defined by stakeholders ➢ Reflective practice is viewed as being cognisant of lessons learned from past projects and apply to future project design	➢ Reflection is a fundamental ingredient of an effective manager ➢ Reflection improve practice ➢ Continuous improvement of their practitioners	➢ A joint (contractor / consultant / client) lessons-learned matrix is developed at the end of each project ➢ Identifies causes and possible solutions in future projects	➢ Time constraints do not permit reflective practice	➢ Nobody knows everything ➢ Everybody learns off each other
24	A successful building services engineering entity achieves client satisfaction, provides technically sound professional services and maintains a supportive and rewarding working environment for its staff. ***Describe your team's unique qualities and abilities which you believe contribute to a successful working environment.***	➢ Offer technically sound professional services ➢ Produce good quality detailed designs as opposed to relying on contractors and vendors to provide an element of design ➢ Pragmatic in the sense of being hand-on, practical, on-the-ground solving problems with the contracts and client ➢ Disadvantage is that competivitly low fees restrict this pragmatic approach	➢ Bring people together to understand what they are doing ➢ Ascertain their different qualities and the different attributes ➢ People of the same mindset to interact ➢ People have different opinions, but the same end goal	➢ Construction can be a stressful working environment ➢ Open communication culture which has been developed within the team promotes an enjoyable work environment ➢ Aids to positive mental health of practitioners ➢ Understanding that a healthy work/life balance is to be maintained.	➢ Communication, honesty and hard-working	➢ Multiple angles to a situation ➢ A collaborate multidisciplinary team working environment
25	The use of design decision-making tools in the propensity of power distribution, general and emergency lighting, lifts, lightning protection, heating, ventilation and daylight simulations, wind and solar energy, etc. may be useful for guidance. ***In your professional experience, how accurate are decision-making tools in your specialism?***	➢ Engineering design software packages are very useful tools, but engineers are over-reliant on them ➢ Computational fluid dynamics (CDF) does not reflect real-world, and is dependent on accurate input parameters (difficult to determine) to simulate a realistic model ➢ Thermal Modelling (TM) is a good guidance but reliance on many variables at the outset, that is, people behaviour, building operation, weather conditions, building construction materials	➢ Reasonably accurate with actual experience of the user ➢ Ability to interrogate the output of these decision-making tools as good as the user applying the software	➢ Digital software is a good design tool ➢ Understanding of the basics is required to analysis the results to ensure no human errors occurred during data input	➢ Caution on the accuracy of real input parameter	➢ Users of digital tools require experience and understanding the practicality ➢ Caution of over-designing

26	Building Information Modelling (BIM) is not just a fancy 3-d model. It is about moving away from traditional industry practices of producing multiple and independent paper-based documents that describe what a building is, towards creating virtual buildings. ***Describe your challenges during the transition from 2-D to 3-D modelling during the design process.***	➢ Greater coordination of disciplines' design is required during the design process ➢ Traditionally, 2-D designs were produced by engineers, and its installation co-ordinated on site by others at construction stage. Nowadays, the design is intended to be installed as per the 3-D model ➢ Additional time coordinating the 3-D model incurs costs to the design team	➢ Challenge in upskilling personnel ➢ Analogy from pencil drawing to AutoCAD as from 2-D to 3-D ➢ Improved output from training trades-person in BIM to facilitate technical coordination	➢ Flow of information to generate the model is problematic ➢ Drawings are generally required in advance of final design and/or equipment approval, resulting in much to be interpolated	➢ 2-D to 3-D transition is ongoing	➢ 2-D supports constructible drawings for progression and buildability ➢ 3-D supports clash resolution, design construction coordination
27	MagiCAD offers integral BIM 3-d software for building services engineering design. It is a powerful enhancement tool developed to save time with more user-friendly, flexible, intelligent, and parametrical user environment. ***How has your experience been thus far?***	➢ Major challenge using MagiCAD is symbology ➢ Potential to save time during the design process but requires significant training for designers, BIM/Revit technologists and installation contractors	➢ N/A	➢ Much need support in design ➢ Integrate both practitioners and technologists into one role, developing the skill-set of both, as opposed to the traditional two-people team	➢ N/A	➢ N/A
28	Inefficiencies in engineering practice at design stage are noted as follows; lack of design coordination between disciplines leading to installability issues, poor communication, deficient or missing input information, duplication of effort, unbalanced resource allocation, erratic decision-making, and poor design quality As the design process is found to be a major source of problems at construction stage, even to the extent of undermining systematic management, the following deficiencies were identified: inferior quality of installation, time delay of installation, increased cost of installation, and redesign. As a direct consequence of these deficiencies, the impact in design consultancy practices is significant. The primary dysfunctions relate to: professional dissonance, poor design quality, redesign programme, and redesign cost. ***How has your organisation dealt with practice dysfunction?***	➢ Design engineers are totally dependent on software for major calculations ➢ Excel based calculation are deemed manual ➢ Greater number of site visits are required for existing building refurbishments ➢ Life cycle consideration are imperative from a sustainability and energy efficient perspective ➢ Understanding the stakeholder's requirements is key to delivering a a successful project	➢ BIM process will minimize inefficiencies and deficiencies at design and construction stages, respectively ➢ Visualization allow the project team to walk-through the end-product	➢ Declined to respond	➢ Inevitable design changes from design shortcomings or direct client request incurs significant cost at construction stage	➢ Early client-project team engagement miminises design gaps, rework, additional costs, thus maximizing installation quality

Appendix 19 *Validation interview framework*

NR	INTERVIEW QUESTION	PEOPLE	PROCESSES	TECHNOLOGY
1	The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design. *How is your practice embracing digital engineering?*			*
2	The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice. *What is your experience of the phenomenon in practice?*		*	
3	BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates. *How is your practice providing practitioner training in adopting new digital technology?*			*
4	Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify. *What is your practice's experience thus far in applying BIM to projects at design and construction stages?*			*
5	The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources. *What is your experience with the accuracy of these prediction software tools?*			*

NR	INTERVIEW QUESTION	PEOPLE	PROCESSES	TECHNOLOGY
6	The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction. *By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?*			*
7	Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare. *How do you envisage your practice accelerating digital transformation to expand digital solutions?*		*	
8	BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage. *Has your practice experienced this work phenomenon?*	*		
9	The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process. *How does your practice ensure accurate technical coordination at design stage?*		*	
10	BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others. *What is your practice's protocol in delivering design coordination?*		*	

NR	INTERVIEW QUESTION	PEOPLE	PROCESSES	TECHNOLOGY
11	The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world. *How has your practice bridged the gap between graduate experience and employment reality?*	*		
12	BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset. *How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?*	*		
13	Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time. *How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?*			*
14	The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process. *What extent is your practice reliant on predictive modelling?*			*
15	The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice. *Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?*	*	*	*

Appendix 20 *Vaildation interview participant transcripts (External – BSE management)*

Reference *Engineering Management*

Attendees *Managing Director (BSE Nr1), Raymond Reilly*

Date/Time *19th December 2019, 7.30am*

Venue *BSE Nr 1 Offices*

Participant Nr *1 (BSE1 Managing Director)*

Question Nr 1. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design.

How is your practice embracing digital engineering?

Response Well I suppose two bits to it, there's the statement in relation to the increasing complexity of modern Irish buildings. They've always been complex. I question whether there is a productivity gap or there's a particular issue. But the question about embracing the digital engineering; it's evolving. I had a conversation only yesterday with somebody saying, 'Jesus, we've managed to get through the last 30 years without having any particular digital engineering and we did a very good job'. And it's questionable as to how it increases productivity at the moment, but we'll see. But yeah, look it's there. We've no choice but to embrace. Is it there yet? No, but we will be embracing some aspects of the digital engineering. So, it's a learning process but we're getting there.

Question Nr 2 The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice.

What is your experience of the phenomenon in practice?

Response That's one bad design team. I must admit we don't. I would have a negative experience. I believe what we do is actually very good as a product. So, you have an obligation as a consulting engineer, as all design team members do, to ensure your design mitigates any potential for increased costs, time delays at the construction stage. So, I don't believe such large deficiencies actually exist and if they do, I don't have a huge experience of it because that's not the type of thing we do.

Question Nr 3 **BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates.**

How is your practice providing practitioner training in adopting new digital technology?

Response Well, as packages become available, we tend to bring in service providers from a CPD point of view to get staff up to speed in the new technologies that are available. Management, as in ourselves, tend to vet products that come in to see how applicable they are to what we're trying to do. Some products that have come in haven't been very good at all, some products have potential and we sort of progress on that basis.

Question Nr 4 Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify.

What is your practice's experience thus far in applying BIM to projects at design and construction stages?

Response God I could be here all day on that one. Personally, I'm not a big fan of BIM. It cost me money as a practitioner because it takes the equivalent CAD operator three times longer to do it in BIM than he ever had to do it in AutoCAD and I don't get paid any more money for it, nor is the industry willing to pay for it. We don't necessarily see the benefit from the consultancy point of view. I can see the benefit from a contracting point of view but we're paying for that to happen. So, and I'm also aware because I sit on the ACEI Committee that does BIM and there is going to be an advice note to all members at the moment which goes along the lines of do plantrooms, routes and risers but don't do anything else.

Question Nr 5 The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources.

What is your experience with the accuracy of these prediction software tools?

Response We've had positive experience. We certainly do; any software we use has to be independently validated and verified. So, any software tools we do use would have an independent validation certificate and we tend to use the ones that are recognised in the market. We're open to looking at new ones but I believe, and we tend to use them extensively, that the accuracy is good.

Question Nr 6 The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction.

By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?

Response I would agree with that. We like the idea of virtual augmented reality. We have done a few schemes where we have immersed the client in a plant room, in an office, we utilise it for presentation purposes. I'm a firm believer that the average client doesn't understand drawings. They are much better at being given something in 3D so they can physically see what they're getting involved in and yeah, we embrace and we believe in virtual and augmented reality technologies.

Question Nr 7 Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

How do you envisage your practice accelerating digital transformation to expand digital solutions?

Response It's a tricky one to the extent that that type of advancement is more suited to the larger practices who have sort of R&D departments within that. It's a bit more difficult for the smaller indigenous practices as we call ourselves, because of the investment required. So, it's a slower progress than we'd like it to be but that's purely cost driven.

Question Nr 8 BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage.

Has your practice experienced this work phenomenon?

Response That's an interesting one with the silos. Yeah, we're very hands on so we have a lot of experience, so we do, and communication is the key driver to getting a successful project. So, we try avoid working in the silos and ensure that there's interface throughout with all the disciplines. We actively pursue that in any project. I think it's critical for a successful project. So, we would try and keep them out of the silos.

Question Nr 9 The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process.
How does your practice ensure accurate technical coordination at design stage?

Response Well it's your obligation, you're under contract to do that. My own experience from my own practice in relation to what we do is that the product we produce at design/tender stage is complete. The Government form of contract requires it to be fully coordinated whether you're doing a Government job or it's a private job, you do it anyway and that's where you invest your time and your energy. And all the design tools you have to allow you get a fully coordinated design with both other design team practitioners and disciplines and then to ensure that the contractor doesn't have to because contractors don't have design experience, they build, they don't design and they're not exactly the best in the world at coordinating or rectifying. We tend to find that the experience on the contracting side is quite poor at the moment and the level of staff they have is poor compared to the experience that's available, like a civic engineer's office. So, we would consider it our obligation of the contract to get a coordinated design out.

Question Nr 10 BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

What is your practice's protocol in delivering design coordination?

Response Interesting one because BIM technologists aren't engineers and they can't actually, in my view, design. They can't design and they don't necessarily coordinate. I'd almost call them digital tracers. So, it's the engineer's role or obligation or requirement to ensure that whatever he produces is designed and coordinated correctly. The BIM technologist is literally putting on paper what the engineer's designed. He can't design it and my experience of BIM technologists is that they aren't designers and they are electronic drawers which they can manipulate things but that have none of the design responsibility. So, our practice protocol is it's the engineer's responsibility to ensure the BIM technologist has done his job correctly.

Question Nr 11 The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world.

How has your practice bridged the gap between graduate experience and employment reality?

Response Another good point and it's something we're actively pursuing with, well I think they're called University now, but my days Dublin Institute of Technology in the Engineering Department, there's quite a bit of interaction with the engineering department at the moment because we do review graduates as they come out. They aren't as experienced in digital or reality as we thought they would be, or digitalisation of engineering and we think it's important for the consulting engineering practices to engage with the colleges to ensure what comes out is what we're looking for so that we're not training them from scratch when they come in. And I know it's an issue we all experience. So, there's quite a big interaction at the moment between practices and college to get a better version of a graduate that is more suited to what we're looking for. So, that's what we tend to, because otherwise we end up having to train them ourselves and then you train them and they go on somewhere else.

Question Nr 12 BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?

Response Well the so-called half life of technical knowledge, the basics are the same. The engineering concepts and designs are still the same and the background engineering is still the same. So, all you're doing is advancing the tools you use to express your experience and your design and any digital tool has a life and eventually expires. So, it's to keep up to date with what you think is the best tool to apply your knowledge. We tend to evaluate them as they come in and go through them but we haven't had a situation where you have a one- or two-year life, they tend to last almost a generation before you come out again the other side. So, it's not something that's got a big turnover. It hasn't affected us too greatly as of to date. But we do like to think we're kept abreast of all advances in digitalisation in the industry.

Question Nr 13 Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide

visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.

How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?

Response Well you've a good point there in relation to trying to poach previous information and as we are ISO9000 we have set standards as to how design is set up. We do not like the idea of poaching from other projects in the practice because that leads to risk of mistake. So, everything has to be started from scratch. That's how we work through our process. That's what we're obliged to do. It's sometimes difficult to police but that's what has to happen to mitigate any risk of mistake and it is a difficult one to manage. The management systems can help that in that you do tend to upload information to collaborate with other team members but the information you upload has to be correct for the project.

Question Nr 14 The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

What extent is your practice reliant on predictive modelling?

Response I wouldn't say I'm reliant on it at all. Actually, before any software we use had to be independently validated in accordance with ISO procedures so any software we do use we'd have confidence on that the result would be correct. So, we wouldn't have a huge reliance on predictive modelling but we do have a huge reliance on accurate engineering.

Question Nr 15 The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice.

Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?

Response I think ultimately digital engineering has to be integrated into your practice to survive. It'll end up being, Jesus middle of the road what's here at some stage, doing out jobs for us. I suppose go back to the old story, many years ago my father, when the computers came out and he said, 'Is there two buttons; one for mechanical and one for electrical?', and maybe that's the way it's going finally. But look, yeah, it doesn't take away from the fact that you have to have an engineer with knowledge to allow any software package or digital engineering package to work effectively. So, the engineer inputting it has to have a knowledge and be confident in what's coming out and not just be reliant on the result and saying the computer is right. So, yeah, it doesn't take away from experience in relation to, or good engineering design, but you do have to embrace technology as it comes in.

Reference	*Engineering Management*
Attendees	*Managing Director (BSE Nr2), Raymond Reilly*
Date/Time	*19th December 2019, 1.30pm*
Venue	*BSE Nr 2 Offices*
Participant Nr	*2 (BSE2 Managing Director)*

Question Nr 1. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design.

How is your practice embracing digital engineering?

Response Okay. I think we've obviously been; we've been resourcing heavily over the past I suppose six, seven years in deciding on BIM. So, obviously we're designing in the 3D environment now. Which I suppose we had to, I think as an industry or as a profession we went from designing on 2D to 3D which I think was a huge jump for the industry. I'd like to think that we're probably a little bit ahead of some of our peers on that. But it's a huge learning curve, it's a huge resource. But I think we, as a practice, we're probably on the other side of the curve now at this stage so I would say 80% to 90% of our projects would be delivered on 3D at this stage. I think in terms of the digital engineering aspect of it, I think that you know, because in terms of compliance that buildings have to achieve, you know, quite onerous compliance these days that there has to be a very conceptual engineering approach from the outset. Because I think gone are the days when an architect could hand you a building and then you know, we were trying to force or hammer in M&E design solutions just to respond to a problem. I think nowadays I suppose there's a slow realisation that the architecture profession needs input at a very early stage to inform concept in terms of building fabrics, in terms of system integration. So, I think that's how we've, and I suppose from that we've kind of got a lot of different specialisms now with informing very early stage concept design which we always did really, which was the analysis, thermal analysis, dynamic thermal analysis. But also, we're doing a lot more in terms of wind analysis, using CFD, daylighting, sun lighting, penetration. So, you know those type of dynamic modelling approaches would be kind of core to a lot of our projects at this stage.

Question Nr 2 The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice.

What is your experience of the phenomenon in practice?

Response I don't think this is a new phenomenon, I'll be honest with you. I think that, I honestly believe that as a profession I think we have sold ourselves short. I think that, and this trend I think started happening 20, 25 years ago where consultant engineers should be the professional and should be leading the design process and I think through trying to be competitive on fees there was this move started in the industry to try and push across design liability, design responsibility to the contracting side. So, I think as a practice what we have always tried to do is to pride ourselves on our own level of detail and what we would offer in terms of design and detail and making sure that's incorporated into the design at an early stage. So, we have a very simple philosophy which you know, we try to, you know, instil in our engineers which is design it once and design it right and that's how we've tried to tackle it, you know. Now you will obvio0usly get incidents where, you know, you have architects and you'll see the architects will always continue to design you know, but it's how really you manage that and how you make provision for that in the design you know. So, that's my experience.

Question Nr 3 **BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates.**

How is your practice providing practitioner training in adopting new digital technology?

Response Well I absolutely agree with the statement. I think that you know, I think that the industry, the building services engineering practices have been quite slow to adopt the, you know, the digital design techniques such as you know, designing in the 3D world. Using BIM for want of a better term. I think that, you know, we made a conscious decision to make that jump you know six or seven years ago and I suppose we've consciously built a team. I suppose there's two aspects to this, I think obviously it's the team that delivers and models in BIM but then it's also ensuring that your engineers can design in a 3D world. That they can interrogate a 3D model, that they know how to do that. That they've got the technology and they've got the, you know, they've got the tools and the equipment to go in and have a look at a 3D model. And I think that's how we tackle that. Now, the other thing in terms of training, what we have here is we've got an established graduate training programme here which is accredited with 2D. So, we have, so any of the new graduates that come in here are trained in the types of concept modelling that we would do which is you know, I mentioned this; thermal analysis, dynamic modelling, daylighting. They're also trained in BIM and using Revit and they're trained in how to walk around, how to look through a model in terms of the coordination. So we, so this is kind of a structured training programme that we have developed here and I think that's the way we've dealt with it.

Question Nr 4 Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify.

What is your practice's experience thus far in applying BIM to projects at design and construction stages?

Response Okay, well we've spoken a bit about BIM already. But I suppose what I said is we went through a very difficult upward implementation of BIM which I think is no different to any practice but we had to resource it heavily and we had to change the way we think and the way we design. Not just the engineers but also the drafters who are now obviously BIM Modellers. So, I think we are, you know, I feel that in the industry that we are a little bit ahead of our competitors. I'd like to think that we, you know, we kind of always try to do that. So, in terms of BIM at project design, as I say this is the stage we are, you know, 80% to 90% of our projects will be delivered on BIM and I think at this stage that we have such a strong track record in BIM that we actually get a lot of efficiencies from it. More so that we would have when we were offering projects in 2D. So, you know, I think it's a case of once you make the leap across to being fully BIM compliant, it's at that stage them you start realising the efficiencies of it because there is efficiencies to be realised you know. To a point now where, if we are quoting for a job we would nearly, I hear other consultancies or competitors saying that they charge extra for producing BIM, well it's quite the opposite for us now if it's a 2D job we'd nearly need to charge extra in terms of it takes us longer to do it because the efficiencies just aren't there for us anymore.

Question Nr 5 The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources.

What is your experience with the accuracy of these prediction software tools?

Response I think, you know, we've been very lucky in that one of the founding partners here, David Walsh, would have been quite at the forefront of this technology 20, 25 years ago. When we started the practice in 2002, you know, David was heavily involved in this and had kind of picked up these types of modelling techniques when he was working in London. So, in terms of, we've been lucky in that we have umpteen projects at this stage that we have modelled and simulated at the design stage and have had the benefit of going back and carrying out post-documents evaluations and seeing how they actually have performed and over the lifetime of their buildings. So, you know, so I think the accuracy will vary slightly but I think the industry has, there is always, clients have always had question marks about the accuracy of this. We have no question marks ourselves because we know the accuracy of our own engineers and particularly the guy who is in charge of the department has never really let us down in that regard. But I think there's certainly an onus on the industry now to go back and carry out proper post-documents evaluations to verify that the initial predictions are correct. I think ultimately, you know, this is a software and it's a tool so it's only as good as the operator at the end of the day.

Question Nr 6 The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction.

By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?

Response Yeah, I mean I think this is stuff we're already involved in. As I say, we've always mentioned that we've been involved in various forms of modelling since the genesis of the practice. We have used VR techniques in some projects to display maybe the complexity of service installations. But I think, you know, I think it's probably not as you know, really how we're using this technology is more in a marketing and a sales-type approach as opposed to assisting stakeholders, truth be told, you know. Because ultimately, you know, the design that we are involved in has to be transcribed into a set of contractual documents at some stage, you know. So, whatever we do in a 3D modelling sense has to then be transferred to a set of drawings to form a contract.

Question Nr 7 Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

How do you envisage your practice accelerating digital transformation to expand digital solutions?

Response Yeah, I mean I think in terms of, you know, the digital transformation plan as I say, we've had our own internal digital transformation plan which has been, you know, which has been running for six or seven years. I think that you can't, you know, and we have continually tried to improve the level of detail and the level of quality of deliverables and that ultimately is what I'm saying to you is quality of drawings, you know. Because you know, a model does not form a contractual arrangement, you know, because ultimately, we will have to go out to the market with a set of paper documents you know which is kind of a, it is a little bit of a nonsense as well in reality. But that's the industry that we're in. So, I don't know if, and I don't see that as changing in you know, too quickly because you know we live in a world with solicitors, you know. But in terms of, you know, building and construction I think, you know, we've delivered a number of projects in BIM successfully but I've yet to see the building aftercare elements of it being enhanced by a BIM model let's just say.

Question Nr 8 BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage.

Has your practice experienced this work phenomenon?

Response Yeah, I think if you ask an architect to recommend a good MEP engineer, they'd be very slow to do so. So, I think there is generally a suspicion or, you know, I could even say like a resentment towards B&C practices from the design team, you know. I think it can be viewed by architects and QS's and project managers as a little bit of a black art. So, there's always that suspicion. But I think ultimately you just have to; you have to just overcome that and demonstrate your point through experience and through quality detailed information. I think certainly the 3D BIM product helps that in my view, you know.

Question Nr 9 The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process.

How does your practice ensure accurate technical coordination at design stage?

Response Yeah, as I mentioned to you previously you know, at some stage in the past the industry, so the building services, engineering, design industry sold itself short. I think that they, in a race to try and get some sort of competition they have, you know, I think the service has been downgraded. And as a result there was a move to try and push stuff across to the contracting side for delivery and I think that's even more so evident in the UK construction market where obviously we work in both so we see that quite a lot that the building services engineers will do a very scant concept type design and then hand it across to a contracting side for delivery. Ultimately, the client feel that he's paying a reduced fee for that reduced service but you know, what he doesn't realise that he's paying for it in the long-run, you know. So, I think that, you know, I think it's slightly different in Ireland in that with the regulations, you know with the BCAR regulations, I suppose the move across to contracted delivery has been less so. So, I think that there's, so I think ultimately we try to ensure that there's a good coordinated, well thought out design package that's completed as design stage, simple as that.

Question Nr 10 BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

What is your practice's protocol in delivering design coordination?

Response Yeah, I think you know ultimately, this question is around the old model and the old 2D design model where if you looked at how an architect's practice operates, they would have architects and technicians that will use software tools like CAD or Revit and they will develop a design using you know, directly. Whereas if you look at how a MEP practice works, you know, typically they will use technicians and drafters to develop the design from you know, from red line mark-ups that produced by engineers. We have tried to implement the, how an architect would operate and try to get the engineers more fluent on these, on the software techniques. That's a very difficult implementation particularly with more senior guys. I know some of the junior engineers, or the younger engineers will be more BIM fluent but I suppose the challenge is to try and get the more senior experienced engineers to live in the 3D world. So, we would use tools such as 3D viewers, you know, Navisworks, to try and, number one to try and get the engineers experience, get them involved in the model but also share their experience with the BIM technicians. So, it's just joining that gap.

Question Nr 11 The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world.

How has your practice bridged the gap between graduate experience and employment reality?

Response Yeah, I mean I think that's very true. We've experienced that ourselves. I mean quite recently we were involved with some colleges and they actually hadn't heard of Revit which was amazing, you know. So, I think that ultimately how we, you know, I've already mentioned that we have a graduate training programme here. So, we take in undergraduates and graduates and we expose them to, and absolutely 100% right, they came in with no 3D experience. So, they get a flavour of all the 3D modelling techniques we would use which is thermal analysis, daylight modelling, CFD analysis. But as well as that we would also involve them in how design, mechanical design and electrical design is developed using Revit.

Question Nr 12 BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?

Response I think there's a number of things. I think we obviously have a number of offices so it's really sharing the knowledge between the offices number one, and how we do that is we would often move some of the engineers around for a day or two to try and, you know, get them the benefit of knowledge or experience or techniques being explored in some of the other offices. I think we have to be, as an industry, we have to make time for the dissemination of knowledge and none of us are getting any younger. So, what we would do is, we mentioned already our graduate training programme. That graduate training programme I should say is delivered by the staff into. So, for example I would give lectures, maybe once every six weeks, every eight weeks on maybe some of the softer skills such as meeting techniques. But then, the other engineers would give lectures to the graduates on, you know, some of the more technical aspects and I mentioned already some of the modelling. But also, in terms of, you know, some of the mechanical design or electrical design. So, the engineers effectively are tasked with lecturing and disseminating that knowledge within our own training programme. So, that's been working very well for us.

Question Nr 13 Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.
How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?

Response I suppose we do use, you know, online library services and stuff in terms of industry standards and specifications. I think we have our own process. We've looked at various industry standard-type specifications such as MBS and this type of stuff in the past and we've kind of, you know, came away from them again because I just think their unwieldy and quite unarraignable. Although I see the advantage in terms of mitigating risk. But I think ultimately, you know, in terms of looking at previous projects, we certainly encourage that in terms of our own company but really in terms of our own practice. So, we would quite often have an engineer present and describe a particular project their working on to their peers and to the graduate training programme. Talk about the difficulties they encountered. Talk about what worked, what didn't work. So, I mean I think that's part and parcel of the industry. In terms of the document management systems, you know, I don't believe that we've ever went to a document management system from another project by another practice and you know, took advantage of it. I just, I just don't see how that would be of benefit because we wouldn't be able to substantiate the basis of the design. So, I'm not sure if it's really any benefit at all, you know.

Question Nr 14 The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

What extent is your practice reliant on predictive modelling?

Response Yeah, I think you know, we certainly you know, have invested heavily in calculation software tools but, and you know, it's a very useful thing. It can bring a certain level of accuracy; it certainly provides a certain level of record for the future design interrogation. But ultimately, you know, any design needs to, you know, it's only through experience with the more senior engineers that they will look at a result from a calculation and they're, you know, they will know instinctively whether that's the right result or the wrong result. Whereas a junior engineer that's taking a result off a software package doesn't have enough experience to say whether it's right or wrong. So, it's obviously trying to get the junior engineers, you know, to run the end results past senior guys with experience. So, and ultimately they in turn would get a feel for when something looks wrong or something looks right. I think that still has to, you know, we cannot get away from, you know, from going to senior engineers and using their experience because it's the only way that junior engineers are going to learn.

Question Nr 15 The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice.

Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?

Response Well I think it already has been probably integrated into our practice and as I say we're continually pushing in terms of our own innovation and out own design process. But I think, you know, I think the question is you know, I think ultimately we are and we will always be reliant on the supply chain at construction stage for the quality of the installation and no matter how detailed or how brilliant a digital model or a digital result is, you know, you will always be at the mercy of tradesmen and delivery contractors and they're own QA techniques and their own experience. So, and I think all the modelling in the world is not going to fit that, you know.

Reference	*Engineering Management*
Attendees	*Technical Director (BSE Nr3), Raymond Reilly*
Date/Time	*17th December 2019,7.30pm*
Venue	*Conference call*
Participant Nr	*3 (BSE3 Technical Director)*

Question Nr 1. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design.

How is your practice embracing digital engineering?

Response Okay, well I guess the primary one is obviously BIM, Raymond. So, BIM has become our kind of global standard so like we don't really use Autocad anymore. So, we're using BIM in the true sense of the word in terms of we don't have BIM technicians anymore like we did in old days with separate CAD technicians because I suppose there was junior and project engineers in the office actually work and design in BIM and the model is not just the 3D tool, it's actually the design and coordination tool as well. So, that's the primary thing and I suppose all the calculations and tagging and all that sits into the model. So, again from an efficiency point of view it's, you know, if there's changes made or whatever it's more efficient to get in and adjust that. That's the primary one from a digital perspective. I suppose in terms of broad digital technology, like that's just applied on projects in terms of our approach to digitally enhancing say commercial office buildings or whatever. So, you know, they're more marketable for you know Google or LinkedIn or whatever so. But that perhaps is a tool but more so how we design to suit the market.

Question Nr 2 The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice.

What is your experience of the phenomenon in practice?

Response Sure. I think yeah, I concur with that statement. I suppose as consultants, as MEP consultants we certainly try to get the design nailed down at design stage. I think the trend at the moment is around architectural practices and particularly the industry is busy as a whole but architectural practice, there tends to be a lot of design coordination and detailed design elements that are deferred to the site stage. And that ends up in lack of efficiency in redesign etc. So, I suppose as much as possible we'd like to try and get stuff tied down again. BIM should be able to help with that if it's adopted early in the process and adopted by the entire design team but yeah, I think that's a challenge and I agree it does lead to cost issues, programme creep as well and it gives contractors an opportunity to yeah, to make claims for variations and delays so. But the objective should always be to try and have a fully coordinated design at tender stage if possible.

Question Nr 3 **BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates.**

How is your practice providing practitioner training in adopting new digital technology?

Response Sure. Well I suppose it starts at the ground up Raymond. So, I guess we've, ours is probably the same as AECOM has graduate training programmes. So, any of the new graduates that have come into the company over the last couple of years would have a kind of focussed training week on Revit and BIM itself. Then in terms of, I suppose, it kind of overlaps with your QA process in terms of projects. The projects are reviewed at the various project stages and there would be a specific review around digital and BIM as part of that. At the end of a project then we have kind of lessons learned workshop where the whole team sits down and talks about their experiences across multiple headings and again, like digital and BIM and efficiency and that would be one of those headings. And then what the, we have a BIM manager, we've two BIM managers in the team in Dublin and they initiated learning bursts every fortnight.

At lunchtime they have a presentation that people of all grades attend where they just go through a particular topic related to digital and BIM automation, scripting or whatever, and just share that information with everybody. And we also have refresher, we would send members of the team out to external refresher courses as well maybe once a year for, again that's more for junior and project grades. Yeah, that's probably.

Question Nr 4 Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify.

What is your practice's experience thus far in applying BIM to projects at design and construction stages?

Response I guess from an efficiency point of view it's a global policy within Ireland that it has been adopted over the last three or four years. So, it's a must-have. But again, from my project experience the benefits and the efficiency depends on the project type and scale. So, the best example is the National Children's Hospital which was obviously a massive project but there's lots of repetition in there and there's huge efficiency in that and we've really seen that at design stages. That's only starting on site but again, when there's changes made or design developments you know, it's one change in a typical room can be multiplied out in minutes to hundreds of rooms. Again, for smaller projects such as fit-outs, if your doing a fit-out of an office, a single floor you'd probably find that BIM is a bit slow. Like the traditional design, engineering design that you would have done five or ten years ago with just CAD would be quicker in that application but I guess that will come with time over the next five years as the entire industry comes up to speed on BIM and I expect that even the likes of the fit-out example will probably become more efficient. But yeah.

Question Nr 5 The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources.

What is your experience with the accuracy of these prediction software tools?

Response I suppose that's a good question Raymond. It's something actually that's a difficult one to answer because it's something that we probably need to improve on in terms of what we find and it's actually difficult to, in a lot of cases, to go back in and extract the information from operational buildings. It's probably something we need to do more of as an industry and then in Ireland as well we're not particularly good at it I have to say. So, it's hard to actually compare and contrast because all you can do is go by the complaints you get after in terms of is the building performing. But that's not necessarily a good benchmark because it could mean that there's elements of an overdesign and still satisfy the criteria but yeah, sorry we haven't done much benchmarking Raymond, so I'm can't really answer that one.

Question Nr 6 The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction.

By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?

Response Sure. We already have. We've set up in Dublin, we have a VR room with the headset etc. So, it's only a new toy that's come in in the last six months so we've used it primarily for clients as opposed to project partners, design team members or anything. So, we brought in clients who tend to be less technical and we found that gives them a really good appreciation for what you're buying into and that's been the main benefit of it. Just to give the client a feel for the project itself.

Question Nr 7 Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

How do you envisage your practice accelerating digital transformation to expand digital solutions?

Response That's a tricky one. I suppose there are initiatives within Arup around, like the heading of digital transformation is a subject and there is a team appointed to manage that and again, I think the key focus is around BIM still but I suppose in terms of digital transformation it's around assessing our progress in the BIM environment. So, it's back to, it's kind of pulls us back into QA with this kind of taskforce kind of check about how many projects are we successfully delivering in BIM. What's the feedback? Like some of the questions that you're asking around efficiency and fee expenditure and value with the client and stuff like that. So, that's the key element, I think. That's being tracked and it's being benchmarked globally then. How does Ireland or Dublin perform against London or San Francisco or whatever in terms of adoption and embracing BIM and is it being rolled out by clients then in terms of, you know, 4D, 5D etc., you know, and throughout the whole project lifecycle. Try and get that bit of feedback in and try and push that from the outset with our clients.

Question Nr 8 BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage.

Has your practice experienced this work phenomenon?

Response , I suppose Arup is multidisciplinary and I suppose no more than AECOM it's part of the sales pitch is about having everyone under the one roof from a coordination perspective but yeah, it doesn't always happen that way. People do work in silos and we've debated that internally around, I suppose even from a seating plan arrangement. Should an MEP team be on a single floor or should, you know, should there be an area of the floor that has a mix of multiple disciplines that are working on a project basis or just to have people intermingling so the coordination and communication has improved. But yeah, it's a daily challenge trying to improve coordination and collaboration between the disciplines in the office for sure.

Question Nr 9 The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process.

How does your practice ensure accurate technical coordination at design stage?

Response Again, I suppose BIM is proving to be a useful tool again with projects at the moment, just in relation to, you know, standard commercial assets, cellular steel beam structure so just demonstrating coordination of horizontal services within the ceiling going through the structure. It's easier when it's being developed in BIM and Revit, the 3D, it's a better tool. But it's really down to, I suppose, communication I think as well is critical as opposed to the digital side of things. Just making sure that the communication and the meetings, or you're getting something out of the meetings and I do find that you'll always have issues. And yeah, industry has historically relied on good calibre contractors who are getting thinner on the ground at the moment because the industry as a whole is stretched.

Question Nr 10 BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

What is your practice's protocol in delivering design coordination?

Response Yeah, well I suppose what we're doing in Arup as I said at the outset is that, I suppose, we don't really, we have BIM managers but they have an oversight in management. So, there's not, it's not like the traditional, the old engineer passes something to a CAD technician and it's gone. So, the engineers are actually designing in BIM so I suppose it's a single point of responsibility and a single point of failure as well I guess but you do have your QA processes where senior people review it at the end but it is someone passing the baton from A to B. It's all being done by the engineers.

Question Nr 11 The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world.

How has your practice bridged the gap between graduate experience and employment reality?

Response Yeah, I suppose I concur with the comments in terms of the last couple of years like the graduate cohort that are coming out of various, like you know your DIT's and your Trinity's and UCD's are yeah, we have to invest heavily in the training end around BIM and Revit because they're not tooled up at the moment. I'm not sure where the likes of DIT are on that. I believe that the graduates or the students are now tasked with doing, like they have Revit in DIT now so they are actually starting to use it but I think it's relatively new. So, hopefully within the next cycle of the next three or four years they'll be more equipped when they come out.

Question Nr 12 BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?

Response Sure, yeah. Well look, I suppose there is an allocated training budget within the firm and everyone has an allocation of money and time annually. And everybody also has a direct manager so if somebody identifies particular training that they feel they should, that they would benefit from they make an application to their line manager and that's for approval. Similarly if the line manager is part of an appraisal process or whatever, feels that somebody needs to improve on certain areas then that's identified and the training is organised and I suppose all the CPD records are kept in-house as well annually. Arup in London also have an innovation team who circulate kind of newsletters quite frequently just looking at what new trends are and things that they see coming down the line. So, that keeps people up to speed on new trends. There's also newsletters on the heading of BIM and Revit and then there's just the standard kind of stuff we do in MEP with kind of, you know, lunchtime training and you know, manufacturers coming in and talking to you about what's coming up in their product line etc.

Question Nr 13 Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.

How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?

Response Yeah, again I agree with that comment that that is the trend. But yeah, Arup have, what is it called? They've dedicated, I think the title is Knowledge Manager. So, we have a couple of people in the Dublin office who, all they do is keep up to date kind of central, a master of specifications I guess and I suppose they're keeping themselves up to speed on the latest standards, British standards, Irish standards etc., codes. And anytime there are updates then they will update our documents and so if we're starting a new project, like we don't cut and past the last specification, we go into a master document and you start from scratch there. So, yeah, probably not as smart as the rest of the industry in that regard.

Question Nr 14 The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

What extent is your practice reliant on predictive modelling?

Response Yeah, again, something like IES would be our central tool for thermal modelling and energy modelling and I suppose that software is pretty tried and tested but I suppose yeah, rubbish in is rubbish out. So, it depends on who's doing it. So, yeah, no, again it goes back to the QA process and you know senior people are obliged to review models and report before things are published. So, as you said, they can apply the benefits of their industry experience and knowledge and use rule of thumb figures and benchmarking to validate the results to feel in the right ball park.

Question Nr 15 The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice.

Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?

Response Sure, well yeah. So, again the answer is yes and I suppose Arup have already started on the journey as you said earlier, like particularly around BIM and having a dedicated taskforce on digital transformation etc. So, it's already underway, yeah.

Reference	*Engineering Management*
Attendees	*Technical Director (BSE Nr4), Raymond Reilly*
Date/Time	*23th December 2019, 2.30pm*
Venue	*Conference Call*
Participant Nr	*4 (BSE4 Technical Director)*

Question Nr 1. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design.

How is your practice embracing digital engineering?

Response Yeah well, I suppose, I suppose the software packages we are probably like most every other building service, engineering company that with digital file management. And also, trying to go paperless as well, trying to cut down on the amount of paper and kind of information that we try to do it, do it in a general software package and everyone is working on it together. So, it's trying to create energy models and have, and even though it would be directly out of that. So, I suppose what we have done is we're trying to, we're trying to get rid of paper, and doing that through software packages. I don't, I don't think we're even close to getting there yet. I think we are still in the process and the design package or the design process and the building services industry across the board. But it's something that we're trying to, in the last year we have tried to map out our kind of workload. And we have brought in a guy, he has been doing a masters, from Holland, has come in to do that. And then we have been looking at how we apply engineering and the real work that we have been doing. But I suppose it takes more money out of the project because we're just being, we're constantly going back and redoing the work over and over again and it's just, it's something that there's, well even working in Canada or whatever, even the digital engineering we haven't really cracked it to make it work more efficiently for us.I think our biggest problem is that clients now want information quicker, that the design process is being cut and cut and cut. So, we don't have the time to do the engineering as detailed as we want to do it and we're having to try to take short cuts. So, it's trying to get the, to get the efficiency there somewhere, using the software better.

Question Nr 2 The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice.

What is your experience of the phenomenon in practice?

Response Yeah, so I think the productivity gap, I think it's, yeah, what is happening is that I suppose it's human nature that decisions are made late, or people have different opinions, the communication between parties that would lead to the gap forming, and the time required. Okay, so the inherent productivity gap and inferior quality of installation. Yeah, so there is definitely a productivity gap. I mean the, I think because the projects are so multidisciplinary that there are so many different parties involved that there is always gaps. And I think it's, it's saying again to the speed at which we are being asked to produce the tender packages. And, as your first question said, buildings are becoming more complicated, there's more in them. And there is also, there is productivity gaps that I think people aren't quite understanding, they are only getting to grips with some of the space in modelling and the terminology and the expectations, the requirement of that, clients don't necessarily know what they want and they are only feeling their way through it as well. So, we're ending up with gaps and differences in what, what different parties think is being asked for to what is actually delivered. And it's leading to, I suppose it's leading to claims, delayed claims, commercial claims and it's leading to gaps in, in the tender documents as well, clients expecting that they're going to, that they bought something when in actual fact they had only really looked over half of what they think they, or they have only bought half of what they actually think they should have got. So, it does lead to, it does lead to issues. And time is the main thing, if you don't have time to design properly and have the time to do that final coordination, there's always going to be gaps. And clients are ultimately, they are paying, they are paying for it.

Question Nr 3 **BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates.**

How is your practice providing practitioner training in adopting new digital technology?

Response Yeah, I think there's probably a lot on the job learning for an awful lot of people. Building service engineering, the third level courses aren't really coming out with guys that have touched on kind of using some of the packages, some of the digital engineering packages like the simulation software. So, they will have used some packages but never really at a very great level. And then in terms of kind of work, Engineers Ireland or API providing support around it, they are few and far between and really focused on the architectural, the structural side of things more so than the building services. So, most of our guys are, they are learning from each other, they are learning on projects and it is, I suppose it does lead to probably a lack of in-depth knowledge in the industry and I know ACI are trying to put together an industry-wide acceptance on what level of design. And it's to try to create an industry wide acceptance in terms of what technology at different stages and how, how we can kind of protect ourselves to make sure that there is a, that there is a common, a common level that every consultant will work to and agree to and that we don't get railroaded by clients to provide different levels at different stages. It's just probably going to help us alone.

Question Nr 4 Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify.

What is your practice's experience thus far in applying BIM to projects at design and construction stages?

Response I think it really does vary between projects. At the moment, one of our main projects involves probably three different architectural partners and ourselves, so where there is a big complex team like that, we're seeing, we're sharing the pilot stuff online and we are all in different countries, it works really well but you can see the, it's the only way to run a project like that. Whereas, trying to apply BIM to an existing building where there is no real accurate information about the building, it doesn't really us offer us any advantage so we're back to CAD. So, I think, I still think there is, there is probably a time and a date for the old reliable CAD and then there is certainly the bigger core complex multidisciplinary projects, new builds, BIM and using it early.

Question Nr 5 The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources.

What is your experience with the accuracy of these prediction software tools?

Response I think a lot of that probably falls backs to the training and expertise, the people that are using them. Overall, the packages are excellent when used correctly. But we do find that we are having to, particularly the thermal energy software, what we're having to do there is manage that through one, one associate director that is looking after IES and he is making sure that from a quality assurance point of view, he found that when it was done each team was doing their own IES monitoring, that there was, that they really, varied, various levels of accuracy at, of input data that was leading to shortfalls, so it really depends on the captaincy of the engineer using it. And that would apply across all disciplines There is, over the years you'd see guys who don't necessarily know what they're putting in and applying, putting in information incorrectly just equal to poor results, poor performance of the building later on.

Question Nr 6 The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction.

By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?

Response We do, yes, and we'll say particularly for the client particularly how the services fit in with your interior architects and clients, they love to see the walkthrough model, and we have done that quite a lot for the more complex fitouts, particularly where there is a lot of kind of bespoke lights, that the architect wants to see how their vision is going to be implemented by us in our design. I see some architects using, are now getting these virtual reality goggles where they can outline, walk through the space and it's something I think we're, we're all going to be going towards in the next year or two.

Question Nr 7 Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

How do you envisage your practice accelerating digital transformation to expand digital solutions?

Response I suppose we're probably all, we probably all have the building blocks there, we have all bought the packages, the software, it's how we use that now and use it successfully as an industry. I think we're all getting, I've had good and bad experiences of digital packages and particularly where BIM is now being formulated by the RIAs to trying to provide the industry on guidance on what it is reflective so and how we design BIM. And I think that's going to be the key to I suppose safeguarding engineering consultancy in future from kind of a very wide varied expectation from contractors and architects. So, if we can get a standard document out there, I think everyone will find it a bit smoother and a more successful implementation.

Question Nr 8 BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage.

Has your practice experienced this work phenomenon?

Response Sure, okay so that would be like in a multidisciplinary, you know, that one manager, who has got kind of an oversight to make sure that everyone is talking to each other? Yeah, I think that would have been my, personally I - well that different managers looked after their own interests. And it's senior management structure I think in the company held that. So, a lot of companies like where I'm working now is that wouldn't have multidisciplinary dealing with third parties so we would, I suppose you have to take our own interests initially and it's to prevent risk later on. But we do have, I think it's, it is industry wide. I think what we have to do is, I suppose is settling out the deliverables in early days and having clear employers' requirements, clear deliverables and clear, and having those deliverables clearly spelt out. And a clear brief within the contract document which is not always done and it's often there's gaps and that leads to the risk later on and the issues early on. But certainly, I think there is a better chance that those gaps can be ironed out and worked out better if there is a more collaborative approach to project delivery and not just discipline by discipline.

Question Nr 9 The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process.

How does your practice ensure accurate technical coordination at design stage?

Response I think we would always start with, if we look at the client contract documents and try to spell out what the, if there is an expectation that comes from the client, that we're going back to them early on with the programme and with a set of deliverables and get them signed off and approved. And then it's going through stage by stage because we have a sign off procedure. So that a team designer producing, a team designer explaining to them how the systems will look and feel, giving them conceptual, giving them rendered views of spaces, so that they can visualise what it is we're trying to do and trying to get that feedback early on. And I think it's stage, stage feedback is really important, that it's not waiting until we have a full tender design pack together. And also, it's trying to, it's trying to, from experience, having experienced senior people on the project who will fill the gaps. For instance in rainwater design, specialist lighting, you name it, there is so many areas where there is potential gaps and it's really through experience that I think building services engineers, what those are kind of advising the client early on and let's say kind of minimise the risk of those onsite deficits.

Question Nr 10 BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

What is your practice's protocol in delivering design coordination?

Response It is, I suppose primarily what we do is we are reliant on the technologists to do the coordination for us and we are reliant on them to have a certain level of experience to be able to do that. Because it's all well and good to kind of move the pipes and the ducts around, but if you don't understand how to set out pipe work and ducts work and how it simply functions, it leads to issues later on. So, I think where we leave it just to the technologists to do it, we have problems onsite and the contractors will come back and say that it hasn't been detailed to enough detail for them. But where the engineers have gone in and viewed it in Naviswork, out of a kind of a benchmark area for the technologists to follow, you find that the end result is a lot better. But it does take a lot more time to do it that way and sometimes we don't have the time, we're not given the time to do that by the clients, they're happy enough for us to pass it on to the contactor to do that coordination element.

Question Nr 11 The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world.

How has your practice bridged the gap between graduate experience and employment reality?

Response Yeah, I think certainly there is a bit of a deficit there. The graduates are coming in with limited experience of BIM. And it does vary from institute to institute as to how much, what they can they do on based on the likes of the other digital engineering packages. But what we have tried to do early on is, we're trying to get our graduates to open up, work in, try to design their systems and set out their tasks, instead of passing it over to the technologists, that it's done directly by them. And with varying degrees of success, we do find that it does take an awful lot longer for graduates to do that and sometimes it hasn't been the most efficient. So, really where we see a graduate, with a natural kind of ability to it, we'll let them work on it. Others though, we're nearly quicker to, to keep them in 2D and then pass it over, pass it over to a technologist who can put it into 3D a lot quicker and a lot more correctly than they can. So, it does, it varies massively on projects.

Question Nr 12 BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?

Response Yeah, I suppose what we do is we've got a set out, we employ key personnel. So, there is two people feeding this, and are kind of representing us to the ACEI I in terms of how we implement BIM in projects. And so generally what we try to is pick out associate director/director level, and take that on. And then in terms of innovation and that, we work quite heavily with the IDA and Enterprise Ireland. And there are various courses there that we are looking at in terms of, we are looking at our company about, over 10 years in business , and what we are finding is that we are getting to probably a plateau level in terms of our growth. And now we're looking at it, well how do you innovate it to bring the company on. At that stage, we do that through bringing in third party, bringing in experts to try to help us figure out how to roll with it and how to bring in new technology, being in new business streams that will drive the business on now to the next five years.

Question Nr 13 Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.

How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?

Response It is definitely, yeah, oh it is. And it's things like not using standards when we should, different things like fire duct work and that, it happens all the time. And what we, what we try to do is we, between the, in the company for the applications, to take them and to try to update them that we will get somebody to go through them and review the standards and try to update each of them to make sure that they are the latest and greatest. But it's, the busier we are, the less we do it and the more we copy and paste it. And I think it only becomes apparent when there's an issue on a project and we have to go back and try to, to find the saving, to find the saving standard to get us out of a hole and we realise that we've got an old standard reference in the specification. So yeah, it's a common problem.

Question Nr 14 The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

What extent is your practice reliant on predictive modelling?

Response Yeah, it's one that I think that on the electrical side, we look a lot of the electrical modelling software. So, probably certainly at the front level calculations that, it's not something I'm not directly involved in at all. As you know, Raymond. It's the - what's generally the younger engineers when they're, the more junior grade engineers, they are doing that analysis and it does get passed over to senior engineers to have a look at it. And it's amazing the length of reliance that they have on the younger engineers, we'll say, having the software and the comfort it provides them when they put in, it's the same as external modelling, bad information going in, leads to bad information out, but that that bad information out, they don't have the experience to see that there's an issue with it. Whereas, the more experienced engineers are more senior project engineers, you go with that and, but, and spot the gap straightaway. So, it's, you know, it's that, the question then is you always have to be met by a senior engineer because then you've got to smart enough to take account for a poor engineering input.

Question Nr 15 The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice.

Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?

Response Absolutely. I think it's only going to go one way now and I think the contractors who are, I think it has to be through to completion and it's really where digital engineering resides. It needs to be right through the whole life cycle of a construction project. And as an industry, I don't think we are embracing to its fullest capabilities yet, but it's come on, if we think about it, where we have gone from five years ago until now, there's been a huge improvement. Contractors have gotten, we will get better at it and we are seeing things like the use of digital cloud surveys to verify how installed installations match with the coordinated layouts and that. So, we are seeing kind of that from the drawing board or from the BIM model, right through to, as installed, it's going to become more joined up to digital packages over the, over the next couple of years which will be an improvement for digital technology.

Reference	*Engineering Management*
Attendees	*Technical Director (BSE Nr5), Raymond Reilly*
Date/Time	*10 January 2020, 1.30pm*
Venue	*Conference Call*
Participant Nr	*5 (BSE5 Technical Director)*

Question Nr 1. The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design.

How is your practice embracing digital engineering?

Response Well, I think we have got a big spend haven't we now, for trying to alternate our drawing production which also includes a number of design tools which are already integrated in there. It is the only way we can actually try and make a better profit I think going forward. So, it is very important to us. The answer is, we are investing in doing that now which we should probably have invested in a few more years ago. Maybe the technology wasn't even around then.

Question Nr 2 The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice.

What is your experience of the phenomenon in practice?

Response I think it varies. It is very much dependent on the engineers involved in the company. Those with experience of having seen a job and understand the problems on site will tend to minimise any inefficiencies in their designs, so they don't repeat the same problem on site. Where some companies might be using a lot more junior staff because of the reduction in fees, which is a problem with asking us to deliver a professional job with non-professional fees.

Question Nr 3 **BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates.**

How is your practice providing practitioner training in adopting new digital technology?

Response Okay. So, in terms of how the practice is doing it, we are now rolling out a complete training programme on how to use 3D to every single engineer in the company. We also have a number of, just as you mentioned, more specialist, or engineers that have embraced the technology and the use of the tools. And we are using those to train our own internally but obviously that can sometimes be more independent which is why the company is doing a more global effort now wide effort.

Question Nr 4 Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify.

What is your practice's experience thus far in applying BIM to projects at design and construction stages?

Response I think presently using BIM is still costing us more money to implement. If it is done right, it should save us in the long run in terms of there should be less issues of co-ordination and problems later on during the construction period. So, we should be able to hopefully try and spend a bit less fee then.

That would be the ideal. In terms of cost for everybody else, I think it would be very similar to that. I think there is still very much a lack of understanding of BIM in the construction industry. We are asked to provide BIM. What they mean is they just want us to draw in 3D, so we are co-ordinated. I think there needs to be more client and non-engineering elements of the industry need to be trained greater in the understanding of what 3D and BIM really means and what benefits it gives from just using it as a buzzword.

Question Nr 5 The BSE design process is aided by the use of computer models which simulate the performance of thermal behaviour, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources.

What is your experience with the accuracy of these prediction software tools?

Response They are all effectively given a quality index, really, you would call them rather than accuracy of the performance and also the rules and regs that you come across, actually after the actual performance they are just getting after a qualitive number. Therefore, on thermal you design to a set of parameters, but that won't mean that it is actually going to deliver any excuse. So, there are now some standards coming through or schemes where you can start actually inputting more data that would be closer to in use energy, but it is still not quite there. Things life roofs where you do a simulation. Again, they are based on a qualitative number, but I think in my experience certainly of software is that they are extremely useful and as long as we actually use the qualitive numbers then the service in the building is generally very acceptable.

Question Nr 6 The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction.

By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?

Response Yes, I think we do believe that, but I am not sure if – it is not there, it is nowhere near there, where we could use it on every project, or every design team or client team actually wants to use it either or pay for it. So, there have been many variants. We could do a very basic version. We could do an intrinsic version. We have the facility. We have done it on some projects, but it has still a little way to go yet particularly for M&E, it is very hard because of the fact that our models are so complex. They are very data hungry and some of the visualisation software and devices that do that, struggle to keep up with M&E where they can restructure the architecture, it is a bit easier and simpler and less complex models.

Question Nr 7 Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare.

How do you envisage your practice accelerating digital transformation to expand digital solutions?

Response Well, I think that we are already trying to do that massively. I am sure there is always more to do. But I think that our first step is to make sure that we are currently spending an awful lot of money producing 3D models and then not utilising them to their best use, because of the data that is inside them. So, the more data we put in them now or make that data going in more automated, the more useful they will become and therefore, again, more cost effective. And by default, the more we utilise some of the digital tools and things like that, other digital tools will come along and the workforce will also be more embraced into the use of digital tools. Which is one of the big goals to achieve.

Question Nr 8 BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage.

Has your practice experienced this work phenomenon?

Response No, I have not come across management putting any restrictions on anything. We are normally more frustrated about actually making sure our guys do actually talk to people out of their discipline, is my answer.

Question Nr 9 The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process.

How does your practice ensure accurate technical coordination at design stage?

Response So, in terms of design co-ordination, I think the stigma about design co-ordination causes bad designs. It might be a good design but it is just not co-ordinated so they could be two quite separate things. But in terms of trying to avoid it, we have designed reviews. We have our own design reviews internally and in most projects and most times they are very encouraged that there is regular co-ordination meetings with each of the main disciplines, together. And digital hopefully allows that to happen a little bit easier as well where we share each other's models and we can see pretty quickly where clashes are occurring.

Question Nr 10 BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the end result is delivered through the hands of others.

What is your practice's protocol in delivering design coordination?

Response There are many practitioners out there that call themselves BIM people and they don't really help with the co-ordination process that much sometimes. In fact, they sometimes hinder it. But in terms of how we would deal with it here, we have people that are skilled in co-ordination and we should always have more of those and there is an emphasis now on getting people that do, do the drawings, that they take responsibility and ownership of their co-ordination. That is obviously probably something that has been around since whenever BIM started in the industry. It is a continuous challenge.

Question Nr 11 The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world.

How has your practice bridged the gap between graduate experience and employment reality?

Response So, I think, from my point of view, and I have been involved with many training schemes and the like, is that I don't think colleges and universities need to be teaching people the practical end of life because generally actually they will always be out-of-date and we will be far more advanced than they can ever try and teach a student. So, I don't really want my graduates trained too much in BIM or it would be an advantage if they have had some experience in it, while doing their projects, but it is more about the fact that we will train them when they come in on the job, as we have always done. The fact we often get a building services engineer. We get a mechanical engineer or an electrical engineer who has never done any building design and we train them. But they have good - what is the most important thing is that they have really good understanding on the fundamentals of their discipline on the basics.

Question Nr 12 BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset.

How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?

Response Well, there are numerous ways of doing it. One is obviously on the job, bringing in supplies to give us CPD events, keeping up-to-date with those items and obviously when you are working on projects and you can work on site as well, your contractors will often be offering alternative solutions which are good alternatives to what we may have always been designing. And quite often they are at the forefront because their suppliers are in the way of being able to get it into the industry stream.

Question Nr 13 Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide

visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time.

How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?

Response Okay, so our specifications – our engineers are supposed to start fresh with their specifications and they are not supposed to cut and paste an old specification. They may obviously, they have no problem in using parts of specifications, but the core data and workmanship courses should be up-to-date because they are kept on our database. Also, we would expect these documents to be part of the review and queried by the co-ordination and the verification team. I would think it is probably a very similar statement for anything actually, any type of document.

Question Nr 14 The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process.

What extent is your practice reliant on predictive modelling?

Response In terms of picking up – we have got our design AI, it is still very much in its early days so there are not huge points that we have and I think the general view is that where we have got some tools that actually do this checking process, it is still very important that we do a manual check as well. That can only complement if you have two checkers doing it, engineers who can both pick up different things.

Question Nr 15 The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice.

Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?

Response The answer is yes, I do, but just when and by how much will be the challenge.

Appendix 21 *Validation interview analysis (External – BSE management)*

NR	INTERVIEW QUESTION	PARTICIPANT 1 *BSE1 Managing Director*	PARTICIPANT 2 *BSE2 Managing Director*	PARTICIPANT 3 *BSE3 Technical Director*	PARTICIPANT 4 *BSE4 Technical Director*	PARTICIPANT 5 *BSE5 Technical Director*
1	The increasing complexity of modern Irish buildings has significantly increased the pressure to improve the performance of the design process. The building services engineering (BSE) industry is wrestling with its productivity gap, and the time has come to embrace innovation. Its practitioners now have the key to unlock the future by the smart use of technology, which has the power to transform how we design. ***How is your practice embracing digital engineering?***	➢ Constant inherent complexity in building design ➢ Digital engineering is evolving ➢ Traditionally non-digital has worked ➢ Caution to digital evolution increasing productivity ➢ Embracing some aspects of digital technology	➢ 3-D BIM uptake since 2012 (90%); 2-D AutoCAD (10%) ➢ Increased resources and upskilling for transition ➢ Practice is on the other side of the adoption curve ➢ Stringent building regulations required early input from BSE discipline leading to an increase number of specialisms in BSE practice ➢ Dynamic modelling at the core of BSE design	➢ 3-D BIM as a global standard ➢ Refrain from use of 2-D AutoCAD ➢ Traditional practitioner and technologist now demands a single entity as BIM process is design and coordination ➢ Use of digital technology to suit the Irish construction market	➢ Digital software with digital file management ➢ Paperless practice environment ➢ Collaborative digital practice mapped to workflow ➢ Digital taskforce to implement digitialisation ➢ Digital engineering design process envisaged	➢ Continual investment in digital engineering tools ➢ Investment is perceived as an expense
2	The inherent productivity gap at design stage leads to inferior quality of systems' installation, increased costs and extended time delays at construction stage. Such deficiencies initiate dysfunction in terms of redesign and associated financial burden in consultancy practice. ***What is your experience of the phenomenon in practice?***	➢ Shortcomings at design stage are instigated by a *bad* design team ➢ Professional obligation to negate deficiencies at construction stage	➢ Not a new phenomenon ➢ BSE practices selling themselves short due to competitive fees ➢ Pride in design and detail at concept design ➢ Design philosophy to design-it-once and design-it-right ➢ Caution with architect's ever-changing design model	➢ BSE practice nail-down design, but final architectural decision at construction stage ➢ Introduction of programme creep and increased costs ➢ Idealy fully coordinated design at tender stage	➢ Human nature initiates late decision-making by difference opinionated multi-disciplinary practitioners ➢ Buiding complexity with shorter design programme which negatively impact design coordination ➢ Client ambiguity at design stage initiates design gaps, thus *differences* in delivery at construction stage leading to claims.	➢ Productivity gap relates to practitioner variance ➢ Practitioner misunderstanding leas to inefficiencies in their design ➢ BSE practices tend to use junior practitioners to deliver design due to fee contraint ➢ Problematic when delivering a professional project with non-professional fees
3	BSE practices are expected to invest heavily in adopting new technology and in training their practitioners to operate that technology efficiently. Sustaining the implementation of digital technologies requires extra effort from practitioners with their openness in delivering quality design in the format of transferable digital information. The adoption process of digital technology is never instantaneous in practice. Instead, it is dependent on management and practitioners who are more apt to embracing new innovates. ***How is your practice providing practitioner training in adopting new digital technology?***	➢ Service providers provide practitioners with continuing professional development seminar as new technologies are available ➢ Caution to new digital technologies in the current market	➢ BSE practices slow to adopt to digital technology ➢ Practitioners ability to interrogate a 3-D model ➢ Structured training programme to upskill practitioners	➢ Training from the ground upward ➢ Graduate training programmes which focus on Revit BIM process ➢ Graduate training programme overlaps with practice quality assurance ➢ Defined stage design review with focus on categorized lessons-learned in digital adoption and BIM ➢ Frequent learning-bursts and refresher training for senior practitioners ➢ Knowledge sharing for all grade practitioners	➢ Significant job-learning as a consequence of unequipped graduates entering the BSE industry ➢ Inadequate training of digital engineering software packages at university ➢ Engineers Ireland tendency to focus on architectural and structural engineering constructs ➢ Cross-disciplinary learning in BSE practice ➢ Lack of in-depth BSE knowledge by other disciplines in the Irish Construction Industry ➢ Association of Consulting Engineers of Ireland in the process of developing an industry standard design process including digitalization (BIM)	➢ Internal digital training programme to all BSE practitioners with external influence ➢ Practitioners embrace digital transformation greater than management ➢ Global effort to embrace digitalisation

					➢ ACEI stipulation will mitigate being railroaded by clients at each project lifecycle stage	
4	Digitalisation is the adoption of digital technology by a practice, and the introduction of BIM represents the BSE industry's moment of digitalisation by changing the way multidisciplinary project teams collaborate at every stage of the project lifecycle to deliver significant efficiency and cost-saving benefits. However, the overall and practical effectiveness of BIM utilisation in practice is difficult to quantify. ***What is your practice's experience thus far in applying BIM to projects at design and construction stages?***	➢ Caution to the adoption of BIM ➢ Threefold resource allocation to adopt BIM compared to AutoCAD ➢ Limited benefit from a consultancy perspective ➢ Greater benefit from contractors' point of view ➢ ACEI recommend BIM for scheme design in consultancy practice	➢ Difficult uptake of BIM by heavy resourcing ➢ Change thinking amongst practitioners and technologists ➢ Leap-of-faith to BIM has introduced efficiencies ➢ Some BSE practices charge additional for BIM delivery	➢ Practice global policy of BIM has introduced efficiencies ➢ Efficiency depends on project type and scale ➢ BIM is advantageous where design involves repetition ➢ BIM is questionable for small fit-out spaces where AutoCAD more suitable ➢ Industry standards to be introduced	➢ BIM adoption dependent on project type and complexity ➢ BIM efficiency is questionable on refurbishment projects where space data is not accurate ➢ BIM is efficient on new large-scale projects	➢ BIM adoption is expensive initially ➢ BSE practices will reap efficiencies if BIM is adopted correctly in term of technical coordination, thus reducing problem at construction stage ➢ Lack of understanding of BIM in the Irish Construction Industry; just requiring a 3-D coordinated model ➢ Client and non-engineering personnel require BIM process training; it's not just a buzzword
5	The BSE design process is aided using computer models which simulate the performance of thermal behavior, energy usage, electrical distribution, artificial lighting, vertical transportation, ventilation and renewable energy resources. ***What is your experience with the accuracy of these prediction software tools****?*	➢ Positive experience ➢ Outcomes need to be independently validated and verified ➢ Open to adopting new digital technologies	➢ Modelled and simulated at the design stage and conducted post-occupancy evaluations to ascertain actual performance ➢ Knowledgeable practitioners in collaboration with predictive modelling technologies	➢ Predictive modelling design to be compared with operational data to access its accuracy ➢ Currently feedback is measured from FM complaints – inappropriate benchmarking	➢ Digital predicative models are accurate when used correctly, but requires careful review from senior practitioners ➢ Captaincy of practitioner dependent and their understanding of input data	➢ Digital software tools are effective, but require inputs from actual qualitative performance of buildings
6	The use of virtual and augmented reality technologies enhances the design review process, immersing practitioners in full scale simulations of the design. This facilitates early identification of issues, increases program surety, better management of risks, minimises rework and reduces issues during construction. ***By blurring the lines between the physical and digital world, does your practice envisage adopting this technology to assist stakeholders in making better-informed decisions with confidence?***	➢ VR and AR adopted for scheme design and presentation purposes ➢ Average client does not understand drawings; 3-D offers a conception of the building's physicality with client involvement	➢ VR adopted for complex design scenarios ➢ Marketing and sales-type approach as opposed to assisting stakeholders	➢ Recent VR adoption for client rather than practitioners ➢ Offers client appreciation of their service purchase	➢ VR/AR principally for client representation of multidisciplinary technical coordination ➢ VA is currently architecturally driven from an aesthetics perspective ➢ VR/AR will be more prevalent in future BSE design	➢ VR/AR accuracy is questionable at present, as it struggles to keep up-to-date with visualization of SBE software and devices in complex data hungry models
7	Developing and implementing a pragmatic and scalable digital transformation plan is the key to drive an enhanced design practice, improving the technical quality of deliverables by disrupting the BSE industry with a new approach to design deliverables, industry procurement, construction and building aftercare. ***How do you envisage your practice accelerating digital transformation to expand digital solutions?***	➢ Accelerating digitalisation suits large practices with R+D departments ➢ Cautionary of implementation cost	➢ BIM model does not form a contractual arrangement ➢ No practical evidence of building aftercare elements enhanced by a BIM model	➢ Taskforce appointed to lead digital transformation in practice ➢ Assessing progression of BIM in practice ➢ BIM adoption with quality assurance in mind ➢ Tracking efficiency, fee-spend whilst adopting BIM and benchmarked with UK/US design practices ➢ Adoption of 4-D/5-D BIM to track the whole project lifecycle for practice/client benefit	➢ Mixed experience with digital software technology ➢ Standardisation of digital transformation to safeguard BSE practice from unrealistic architectural and contractor expectations	➢ Significant investment in producing BIM models at design stage ➢ Accuracy of digital data in BIM modelling is the key goal for BSE practice efficiency ➢ Linking external digital tools to the BIM model will support further adoption and acceptability
8	BSE practitioners acknowledge working in silos albeit cognisant of critical interface requirements between other discipline designs, and argue that this interface is not clearly advocated by management at design stage. ***Has your practice experienced this work phenomenon?***	➢ Small practices tend to be hands-on with greater communication therein ➢ Avoidance of a silo environment delivers a successful project	➢ Architects reluctant to recommend BSE practices due to poor external discipline coordination ➢ Resentment towards BSE practices as their discipline is deemed a *black art* ➢ *Demonstrate through quality and experience; BIM adoption is key*	➢ Multidisciplinary practices advocate in-house technical coordination – theory versus reality is somewhat different ➢ Silos can be created in-house from inappropriate seating arrangement ➢ Ongoing challenge to improve coordination and collaboration between disciplines	➢ Management tend to look after their interests ➢ Establish client brief early to allocate each disciplines' role and responsibilities ➢ Early ironing-out of gaps in multidisciplinary design	➢ Management place high priority on multidisciplinary collaboration to negate a silo working environment

9	The concept that inferior BSE design is a consequence of poor design coordination, which incurs significant programme delays and costs at construction stage not only affects MEP installation, but also traverses to other discipline trades, most notably, the structural engineering and architectural constructs. It is also inferred that there is dependence on good contractors at construction stage to rectify the discipline interface shortcomings initiated during the design process. ***How does your practice ensure accurate technical coordination at design stage?***	➢ BSE practitioner obligation to technically coordinate under the terms of the contract ➢ Public projects demand the design team fully coordinated design at design stage ➢ Private projects demand greater coordination at construction stage; contractors have limited design experience, which is problematic	➢ Perception that BSE practice did scant design in the past and handed-over responsibility to the contractor to deliver ➢ The introduction of Building control amended regulations (BCAR) in Ireland has improved that perception ➢ Technical coordination demands well-thought out design	➢ BIM process is bridging the gap for multidiscipline coordination ➢ Practitioner sole responsibility to ensure that accurate technical coordination occurs in a professional manner ➢ Traditionally the BSE industry has relied on good caliber contractors; this scenario is now *thinning*	➢ Multidisciplinary technical coordination to be signed off by the design team lead to negate design gap, and instill client confidence as the project proceed to the subsequent stage	➢ Industry stigma that design coordination causes bad design ➢ Possibly good design but not coordinated ➢ Regular peer design reviews to ensure technical coordination ➢ Digitalization facilitates prompt reviews of clashes in the model
10	BSE practitioners argue that design coordination is performed primarily by BIM technologists with variable levels of effort and results. This affirmation of sorts surmises that engineering design is coordinated and driven by engineers, but the result is delivered through the hands of others. ***What is your practice's protocol in delivering design coordination?***	➢ BIM technologists are not engineering practitioners - *digital tracers* ➢ Practitioner role and obligation to coordinate design	➢ Concept design by BSE practitioners whilst technicians develop the design in 3-D BIM ➢ BSE fluency in BIM to match Architects' fluency ➢ Challenge to get senior practitioners to lime in the 3-D world	➢ BIM managers manage the BIM process with practitioner responsibility to design in BIM, negating the need for dedicated project technologists ➢ Peer review if BIM design by senior practitioners	➢ BSE practitioner reliance on experienced BIM technologists to conduct coordination ➢ BIM technologist benchmarking to understand the level of coordination required at design stage	➢ Practitioners perceived as hindering the true role of BIM technologists ➢ Experienced BIM technologists' responsibility to coordinate the overall design
11	The Irish educational system does not adequately prepare graduates for digital engineering practice. It is inferred that the lack of practical digital experience in the BSE curriculum is a significant weakness which sees graduates as living in a 2-D world. ***How has your practice bridged the gap between graduate experience and employment reality?***	➢ Graduates neither experienced in digital or reality ➢ Practices to engage with universities to negate practices training from scratch and employ better graduates	➢ Some Irish universities do not train their undergraduates in Revit BIM ➢ BSE practice have introduced BIM training on their graduate training programme	➢ Graduates have limited knowledge in the BIM process ➢ Practices invest heavily in BIM training ➢ Expected to improve in the foreseeable future	➢ Variance between universities ➢ Graduates have limited knowledge on digital engineering software ➢ Intense graduate learning with varying degrees of success ➢ For efficiency purposes, experienced BIM technologists take-on tasks intended for graduates	➢ Limited advantage of BIM training at universities ➢ Universities don't need to teach undergraduates the full practical side of the industry as its content will always *be out-of-date* ➢ Practice responsibility to teach graduates ➢ Graduate need to understand the the fundamentals of their discipline
12	BSE practitioners are cognisant of the so-called half-life of technical knowledge in engineering practice. While most practitioners are normally keen to evade this outdated status, many do not share this vested interest. Practitioners also disclose that project time demands negates sufficient time for adequate formal training to enhance their digital skillset. ***How does your practice harness technological advances to keep abreast with digitialisation in the AEC industry?***	➢ Engineering concepts and designs are the same for half-life ➢ Digital tools turnover is significant; the best tool is applying one's knowledge ➢ Practice must keep abreast of developments in digital technology	➢ Knowledge sharing between BSE practices ➢ Practitioner sharing between BSE practices ➢ Make time for dissemination of knowledge ➢ Practitioners and technologists are tasked with lecturing and training peers	➢ Allocating budget and time for digital training ➢ Management appraisal for practitioner improvement digital programme ➢ Record of practitioner attendance at continual professional development ➢ Manufactures are a good source of keeping up-to-date with digital technology developments	➢ Technical knowledge management appointed to liaise with professional institutes with regard to standardizing BIM in practice ➢ Close liaison with IDA and Enterprise Ireland ➢ Knowledge saturation in BSE practice leading to innovative strategy ➢ External specialists employed to direct an innovative 5-year plan to digital transformation in BSE practice	➢ Keeping up-to-date via external suppliers' continual professional development seminars ➢ Practical experience on site in conjunction with contractor alternative solutions
13	Digital information management systems enable the integration of people, processes and data throughout the project lifecycle, allowing the secure sharing and storage of project information, while enabling practitioners to collaborate effectively and provide visibility into the project to essentially mitigate risk. Practitioners tend to poach as much as 60% to 70% of previous designs, cost and programme information for new projects as a means to minimise documentation production time. ***How does your practice ensure that up-to-date industry standards and specifications are managed and easily accessible by practitioners to mitigate risk in design?***	➢ Adopt ISO 9000 Standards ➢ Poaching leads to risk and mistakes ➢ Practitioners are obliged to start from scratch ➢ Difficult to police poaching amongst practitioners	➢ Online library for up-to-date Standards and regulations ➢ NBS for standard type specifications ➢ Encourage practitioners for reflect on previous design (lessons-lerned) and adopt an innovation design thereafter	➢ Knowledge managers appointed to ensure practitioners keep abreast of latest standards and regulations ➢ KMs responsible for keeping up-to date master MEP specifications	➢ Information management facilitates dissemination of latest standards and building regulations to ensure accurate design ➢ Out-of-date regulatory standards can have a significant impact on design and construction stages	➢ Poaching old specification is not acceptable in practice ➢ Database with latest standards and regulations is managed by the technical verification team

14	The use of digital prediction software tools can often mitigate against human error from manual calculation, and practitioners accept that such software is adopted with an air of caution in terms of accuracy, thus advocating that their design is checked by experienced practitioners who apply their tacitness to this explicit process. ***What extent is your practice reliant on predictive modelling?***	➢ Non-reliance on predictive modelling with greater reliance on accurate the principles of engineering design	➢ Digital software brings accuracy thereon and for future interrogation ➢ Software requires experienced practitioners to understand the correct inputs and predicted outputs	➢ Current software has been tried and tested; rubbish-in, rubbish-out ➢ Quality procedures to ensure that the final design is reviewed by senior practitioners who apply their tacit and explicit knowledge as rules-of-thumb and benchmarking	➢ BSE management over-reliance of practitioner and digital software to produce *comfort* design ➢ Caution in digital engineering design; poor information-in, poor information-out ➢ Digital engineering tools are successful when senior practitioners take responsibility for thorough review at input and outputs stages	➢ AI is in its infancy in BSE practice; manual design checks are imperative to an accurate design ➢ 2-independent peer reviewers required to critique the proposed design
15	The BSE design process is fundamentally a function of the quality of the installed systems at construction stage of which BSE practitioners are in a position to influence; making sense of the complex dichotomy between the design and construction stages that underpins BSE practice highlights imminent changes to improve the current design process through digital engineering, thus sustaining a modern engineering practice. ***Do you envisage that digital engineering can be effectively and permanently integrated into your practice's innovation strategy and design process?***	➢ Digital engineering must be embraced to survive in practice ➢ Practitioners with knowledge to drive and validate the output of digital software	➢ Continually adopting digital innovation in the design process ➢ Reliant on the supply chain at construction stage to deliver a quality installation – at the mercy of tradesmen and contractors	➢ Digital journey will improve the design process ➢ A dedicated taskforce in practice will drive digital transformation; its already underway	➢ Digital engineering resides through the whole project lifecycle ➢ Embrace digital will be a challenge in the Irish Construction Industry ➢ BSE practice in conjunction with contractors offer a more powerful improvement in digital engineering	➢ Digital engineering is imperative for a successful BSE practice ➢ *How* and *when* are the questions