Enhancing Information Quality through Building Information Modelling Implementation within UK Structural Engineering Organisations

Mehdi Bavafa

School of the Built Environment
College of Science and Technology
University of Salford, Salford, UK

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ABREVIATIONS

AEC	Architectural Engineering Construction
BIM	Building Information Modelling
CIS2	Product Data Standards for Structural Steel
COBie	Construction Operations Building Information Exchange
DTD	Document Type Definition
FTP	File Transfer Protocol
HTML	Hyper Text Mark-up Language
HVAC	Heating Ventilation and Air Conditioning
IAI	International Alliance Interoperability
ICT	Information Communication Technologies
IFC	Industry Foundation Classes
IMMC1	Information management map in Case 1
ISO	International Standards Organization
MIS	Management Information System
RDF	Resource Description Framework
RIBA POW	Royal Institute of British Architects Plan of Work
SGML	Standard Generalized Mark-up Language
STPE	Standard for the Exchange of Product Model Data
SWR	Semantic Web Rule
TPS	Transaction Processing System
URIs	Uniform Resources Identifier
WOL	Web Ontology language
XML	Extensible Mark-up Language

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DEDICATION

"I dedicate this piece of research to my dearest father Hossein and dearest mother Farah for all their supports during my work"

DECLARATION

This thesis is submitted under the University of Salford rules and regulations for the award of a PhD degree by research. While the research was in progress, some research findings were published in refereed journals and conference papers prior to this submission (refer to Appendix D). The researcher declares that no portion of the work referred to in this thesis has been submitted in support of an application for another degree of qualification of this, or any other university or institution of learning.

Mehdi Bavafa

ABSTRACT

Information management has been identified as an essential requirement for the structural engineering sector in a highly competitive AEC marketplace. In the field of structural engineering, information management represents a challenging discipline due to several factors such as a lack of clarity in the adoption of novel technologies, the multitude of different and ambiguous standards available, and the lack of human resources readiness. This research demonstrates that information quality plays a very important role in structural engineering information management as poor quality of structural engineering design information leads to reworks and failures in tendering and construction of projects. 80% to 90% of failures in buildings, bridges and other structures result from errors in design. Novel technologies and workflows have to be adopted by structural engineering organisations, which also need to improve the readiness of their human resources to enhance information management during conceptual, detailed and technical design phases. It is but natural for project teams in structural engineering organisations to expect proper quality of information during the bidding procedure, while providing documents for constructors and also while reporting to clients to make assured accurate decisions. A review of relevant literature revealed that Building Information Modelling has a contributory role in addressing the challenges of information management in various disciplines of the AEC industry. However, to ensure effective contribution of BIM on structural engineering information management, a clear determination is needed to improve information quality. Therefore, the aim of this research is to develop a conceptual framework for the adoption of BIM to enhance the quality of information in structural engineering organisations of the UK.

In this research, an interpretivism philosophical position has been adopted that understands the real world and solves related problems over interpretations provided by participants. This research triangulated case study and survey approaches to the investigation of the research objectives in order to enrich confidence in presenting findings. A qualitative and quantitative approaches (or mixed-method approach) were used to thoroughly explore factors that have a key role in developing a framework for improving information within the AEC industry. Data collection involved the use of semi-structured interviews followed by scale questionnaires that were given to design experts in the UK. The qualitative data comprised of 12 interviews with experts performing the role of structural engineers, BIM managers and design managers in two structural engineering departments of two different large multidisciplinary organisations in the UK. In the context of quantitative data collection, 125 respondents replied to the researcher within two months. Finally, both qualitative and quantitative data were analysed and conceptual framework was developed and validated.

This research points out that at present the UK structural industry is dissatisfied with the quality of structural engineering information and holds the opinion that catastrophic failure in the construction process may result from inadequacies in the information management system. From this research, it is evident that the key dimensions for structural engineering information quality can be explained by information accuracy, information accessibility, and information interoperability and information security. This research examined the key criteria that need to be considered while adopting BIM technological tools, workflows and human resources in the context of structural engineering sector. An initial conceptual framework developed by reviewing the existing literature illustrated the potential power of BIM to contribute to the level of information quality management in structural information management. Primary data collected in this research explored the role of crucial factors of BIM implementation in promoting the key dimensions of information quality management. This research contributes to knowledge by developing a conceptual framework which can be implemented in the ACE industry to improve upon information quality by assisting decision makers associated with structural engineering information management to adopt appropriate technological and workflow protocols, and also to ensure organisational human resource readiness in the contest of BIM. Avenues for further research in this area of information quality management in the structural engineering sector were also recommended by this study.

CHAPTER 1. INTRODUCTION

1.1 Research Background

Contributing 7% of the Gross Domestic Product (GDP) and incurring an annual expenditure of £11bn per annum (Cabinet Office, 2011), the construction sector is a major player in the UK economy. Interventions in this sector will thus, have a great impact on the national economy. Review of recent literature and construction industry reports suggests that the construction industry is marred by numerous problems including construction projects being over-budgeted and falling behind schedule. This has been attributed to less than adequate quality of information available to project participants (Latham, 1994, Egan, 2002, Tang, 2001, Bassioni, 2004).

AEC (Architectural Engineering Construction) industry is characterised as an information and knowledge intensive industry (Rezgui, 2001). Many researchers like (Anumba et al., 2004, Yeomans et al., 2006, Shen et al., 2013) have stressed that the AEC industry has a multidisciplinary nature which is coupled with the need to provide all relevant stakeholders with an opportunity to efficiently communicate their knowledge and experience with other project participants. It has been pointed out that the productivity of the AEC project management's decision making process depends to a large extent on the quality of the information (Havelka and Rajkumar, 2006, Lee and Yu, 2012). Information management has also been identified as a significant prerequisite for survival in a competitive AEC marketplace (Construction2025, 2013). The complexity of the industry coupled with the involvement of multidisciplinary teams and heterogeneous information systems have made information management a challenging task in the AEC industry (Chassiakos and Sakellaropoulos, 2008). The AEC industry requires explicit storage and exchange of project information because of the geographically distributed nature of construction work and the involvement of a wide range of multi-disciplinary professionals that creates a variety of communication and co-ordination challenges within a project.

In recent years, various technological innovations, government sponsored and industry lead such as use of BIM being made mandatory as part of UK government initiatives have been introduced to enhance the level of information management ability of the AEC industry (e.g. use of new forms of procurement, contractual arrangements to support better teamwork). However, the lack of clarity in the use of new technologies coupled with the existing variety of ambiguous standards and boundaries brought on by organisational culture have a negative impact on effective information management in the AEC industry (Arnold and Javemick-Will, 2013). Thus there is a great need and intent to contribute to AEC information management by suggesting a comprehensive strategic approach that would cover all technologies, processes and organisational issues.

Defined as a main part of the construction design process, structural engineering utilises information, knowledge and experiences for analysing force-resistance, designing building or other structures, and document preparation of structures (CASE, 2010). Several researchers from past to present have tried to address collaborative distributed communication between the structural engineering sector and other disciplines of the construction project team. Mostly technological solutions have been suggested by these researchers to address collaboration issues in the structural engineering sector. For example, an intelligent agent system has been suggested by Anumba et al. (2002) for improving asynchronous communication between the structural agent and other project teams. Chen et al. (2005) emphasised on shared open information in a web server that can contribute towards collaboration design between structural engineers and architects. Although, several initiatives have been taken to improve different aspects of information management between structural engineering and other disciplines, there is still a need to find solutions for different aspects of structural engineering information management.

It is expected that BIM will address some of the fundamental information management problems (Mena et al., 2008). BIM technologies enable structural engineers and other construction disciplines to exchange information by using single and central data model (Manzione et al., 2011). Timely and correct information can thus help project shareholders to take more rational decisions and reduce mistakes and rework. A multitude of BIM definitions were found in literature review, and these ranged from a very limited scope (defining BIM as a software) to a relatively broad scope (defining BIM as tools and processes for life cycle data management) (Smith and Tardif, 2009, Penttila, 2006). Several perspectives on data such as 2D drawings, 3D objects, 4D time scheduling and 5D costs can be provided by BIM. Additionally, it can provide an approach to share that data through all of the phases of a construction's lifecycle. BIM enables sharing of data through the entire cycle of construction, commencing from the feasibility studies, and including the initial design, detailed design, and implementation and maintenance phases. In spite of being available for over 20 years in the AEC industry, and even though large numbers of UK AEC sectors are aware of the advantages of adopting BIM in the information management process, there is still a lot of resistance to adopt BIM among UK AEC sectors due to a lack of readiness of organisations to implement BIM (Khosrowshahi and Arayici, 2012). This thesis is being presented with an intention to gather a deep understanding of BIM implementation in the structural engineering sector and to address information management challenges faced by this sector by providing clear cut guidelines for the adoption of BIM to manage information and also to enhance the levels of both information and business service quality.

1.2 Problem Statement

In this research, it is argued that information management challenges can be considered under the broad context of information quality. Information quality plays a very critical role in determining the outcome in the structural engineering business, as poor information leads to poor drawings and poor reports either in the bidding phase or the construction phase (Westin and Sein, 2013). Several dimensions of information quality in organisations have been identified in the literature review (Marshal, 2004, Gorla et al., 2010) however, the dimensions for benchmarking the quality of information depend on the use of the information in different organisations. Therefore in the context of structural engineering, there is a great need to identify the key dimensions of information quality and key success factors to achieve high quality of information.

The quality of information either fed into the system or generated by the system determines both accuracy and quality of the output product. It can thus be considered that the characteristics of information in organisations are dependent upon the information quality. Thus, information quality is a target that determines the characteristics of information in organisations. In this research, information management strategies are developed so that the target of information quality may be met.

Poor quality of structural design information causes financial costs and structure failure in the construction industry

Poor quality of structural design contributes to reworks and failure in tendering and construction processes. Construction Industry Institute (CII) indicated that direct costs by reworks is 5% of total construction costs (CII, 2013). Moreover, design errors are estimated within the ranges between 80% to 90% of failures of buildings, bridges and other structures (Lopez et al., 2010). Information quality plays a very critical role in determining the outcome in the structural engineering business, as poor information could lead to poor drawings and poor reports either in the bidding phase or the construction phase (Westin and Sein, 2013). Therefore, a reduction in rework and failures in the construction process may be achieved through improving the quality of information in the structural engineering discipline, particularly in pre-construction and during construction works.

It has been pointed out that structural engineering organisations are one of the major producers of information in the conceptual and detailed design phase (Institution of Structural Engineers, 2014). In this regard, it is worth mentioning that structural engineers have been recognised as being quick to adopt advanced numerical software solutions for their analysis and design processes, however, their applications and procedures are isolated from multi-disciplinary building information management (Wyatt, 2012). In order to survive in the continually changing and fragile global market competition, structural engineers in the UK need to change their traditional methods of information management. Project teams in structural engineering organisations rely on quality of information during the bidding process, to make accurate decisions

Extensive research related to the challenges associated with information management in the AEC sector in developed countries has contributed to a better understanding of the subject. Most of the literature have emphasised upon the requirement for capable collaboration (Anumba et al., 2004, Peansupap and Walker, 2005a, Yeomans et al., 2006, Shen et al., 2013, Xue et al., 2010), distributed information access (Rezgui et al., 2010, Gorla et al., 2010, Zlatanova et al., 2012, Rob et al., 2012) and inefficient adoption of new information technology,(Peansupap and Walker, 2005a, Peansupap and Walker, 2005b, Sheriff, 2011). However, a review of the existing body of knowledge predicted that deep consideration has not been given to investigating the challenges faced by the structural engineering profession, especially in the UK. The limited literature available on information management in the structural engineering sector recognises inefficient information technology support system, inaccurate features of structural documents (Sacks and Barak, 2007, Mora et al., 2008) and lack of control on design document (Aagaard and Pedersen, 2013) as major challenges.

1.3 Research Rational

Impact of BIM on Structural Engineering Professionals needs clear determination:

Despite the potential benefits associated with the adoption of BIM, AEC industry still suffers from low maturity in BIM adoption and implementation (BIM SmartMarket Report, 2009, Meng et al., 2014). The main issue facing the structural engineering discipline is the requirement of being able to function closely and in coordination with the client and other disciplines. This entails that the structural engineering discipline stays up to date with information of materials, loads and geometry in order to identify specific solutions for designing durable, stable, sustainable and economic buildings (Arup, 2015). BIM potentially can contribute to the structural engineering profession by improving their technical modelling advantages, enhancing communication with other disciplines, accelerate design changes which are modified by architects or other disciplines and deliver final reports and drawings to the client and contractors. In this context, recent literature abounds with reports of efforts to develop a framework for BIM to achieve maximum benefits from BIM adoption and implementation. It has been pointed out that BIM has the potential to contribute in assisting structural engineers to create consistent information, collaborative design models within integrated applications and achieve more predictable outcomes (Odeh, 2012). There are numbers of frameworks and road maps for BIM implementation in literature review. For instance, Cerovsek (2011) developed a BIM framework which is presented in IDEF diagram and shows procedures from making 3D models towards publishing 5D models by adopting integrated tools. Porwal and Hewage (2013) developed a collaborative BIM framework for Canadian public construction process. All above mentioned BIM frameworks, present multi-disciplinary collaboration during entire building lifecycle and during the part of lifecycle. Recently published BIM frameworks could show stakeholders a general roadmap to generate and retrieve information during each project phases. Therefore, studies for investigating frameworks for BIM adoption in the structural engineering sector detailing the impact of BIM on information quality in the structural engineering domain are very rare.

Lack of awareness of Perceptions of Structural Engineering Professionals in UK:

The benefits and challenges of BIM need to be investigated in each particular design and construction practice to ensure that any progress in BIM offers benefits for each business sector. In this context, several survey investigations have been published to identify general priorities of construction disciplines in terms of BIM implementation and to convince AEC business sectors to uptake digital well-structured information (NBS, 2014, RIBA BIM4M2, 2014). A survey conducted in the UK has found that one of the main barriers to the adoption of BIM by AEC enterprises is the lack of time and resources to research about their specific requirements in order to incorporate BIM in their business process (RIBA BIM4M2, 2014). Hence, it is essential for each AEC enterprise to access knowledge about their requirements, in the early stages of BIM implementation. In this respect, it is important to mention that the nature of work schedule of structural engineers is significantly different from other AEC enterprises therefore, a study to obtain the perceptions of this industry is necessary.

The UK government is introducing new digital workflows such as Common Data Environment, PAS 1192:2. The impact of these workflows on structural engineering professionals is not evident from existing literature. Although these standards have been adopted by architectural practices, enough attempts have not been made to capture the structural engineering perceptions of existing challenges in managing information and how available BIM dimensions have contributed to address those challenges. This research asserted that there is a serious requirement for a framework to guide decision makers in the field of structural engineering on how to prepare for the adoption of BIM in order to ensure improvement of information quality which is crucial to ensure accurate results in the AEC industry. Formulating a BIM adoption framework by considering literature and current cases in the UK, provides an understanding for decision makers in structural engineering industry to identify specific opportunities among BIM which can be employed to improve their quality of information. Based on the discussions in previous sections, the following aim, objectives and research questions are identified.

1.4 Research Aim and objectives

This research aim is to develop a conceptual framework for the adoption of BIM to enhance the quality of information in structural engineering organisations of the UK.

Key research objectives include:

- To develop a comprehensive understanding of key challenges in structural engineering information management within UK;
- To critically analyse role of BIM to enhance structural engineering information management;
- To examine the relationship between identified key challenges within structural information management and BIM technologies, workflows and human readiness dimensions;
- To develop and validate a conceptual framework for implementing BIM in the UK structural industry to improve information quality management;

Key research questions include:

1- What are the key challenges in structural engineering information management within UK?
2- How BIM is implemented in UK-based structural engineering organisations currently?
3- How can BIM contribute to key information management challenges in the UK-based structural engineering organisations?

1.5 Research Scope

The geographical scope of this research is limited to UK. The UK government announced strong intention to uptake BIM on its projects by 2016. Therefore, structural engineering firms as one of the main partner in design information producing in AEC industry require preparing their selves to work in collaborative BIM-based environment with other disciplines. Additionally there are many structural engineering and construction companies based in the UK, these are leaders in implementing BIM and collaborative design and construction tools and processes. Consequently, it provides this opportunity for this research to investigate their challenges in information management context, requirements and their interpretations of BIM contributions to information management challenges.

The focus of this research is on information management in the UK structural engineering sector with the intent of enhancing the level of information quality. Structural firms conduct force-resistance analysis of structures, design building structure, and do documentation of building design and structure. Analysis, design and technical engineering processes have been excluded from the scope of this research, and the focus is on the key challenges that influence information in the capture, generation, exchange and documentation in structural design organisations. A key emphasis is on integration of structural engineering professions in an integrated design workflow.

The main scope of this research is limited to investigation of information quality management and examining comprehensive knowledge that can cover all technological, process and human resources aspects within structural engineering organisations. BIM is recognised as a method of information management that seeks to improve information quality in the AEC industry. A detailed study of the key challenges of information management in the context of structural engineering has been carried out in this research and the potential of BIM implementation to improve the information quality has been explored. A broad description of the possible benefits of BIM has been described in the literature review, and its categorisation into various maturity levels and steps has been elucidated. The scope of this study has been determined into two different domains of research. Firstly, information quality aspects in the context of structural information management have been developed. Secondly, BIM dimensions that which includes technology, workflow and human resource aspects have been considered as solutions that impact upon information quality in the domain of structural information management.

1.6 Research Approach

This research adopted the interpretivism philosophical paradigm. In the initial stage of this research, current literature relating to the general AEC information management in the context of the structural engineering sector was reviewed in order to identify key challenges. Later stages of literature review identified BIM dimensions as potential solutions for information quality. Empirical data from two structural engineering project cases followed and surveys with experts in the structural engineering, BIM and design management areas were conducted. Multiple sources of evidence for data collection were needed in this research; hence it was supported by multiple case studies among private structural engineering disciplines that had experience in the implementation of BIM. With respect to this, data collection techniques used in this study included interviews and questionnaires. Interviews supported this research in obtaining in-depth information related to information management challenges, level of BIM implementation in organisations and the possible contribution of BIM in practice. Questionnaires added to the data collection by obtaining information from large samples in the industry and by measuring the relationships between concepts that have been explored in the literature review and case studies. Qualitative data collection included 12 interviews of experts performing the roles of structural engineers, BIM managers and design managers. These experts were selected from the structural engineering departments of two different large multidisciplinary organisations in the UK. Quantitative data collection comprised of a web based link questionnaire that was sent to 300 participants across the UK. Representing organisations of various sizes, these participants had active roles in structural engineering information management. 125 respondents representing 46% reverted back to the researcher with their answers within the two month time limit. NVivo 10 software package was used to analyse qualitative data from interviews and SPSS 20 package was applied to analyse quantitative data from the questionnaires. Findings from interviews, questionnaires and literature reviews were used together to develop a conceptual framework. The final phase of this research validated the conceptual framework through interviews with six experts. Their comments were applied to modify the conceptual framework and develop guidelines for practice. The adopted research processes are illustrated in Figure 1-1. This research applied the Define, Measure, Analyse, Improve and Control (DMAIC) process (Anbari, 2002, Lawton and Bass, 2006).

1- Define: In this step, literature related to information management characteristics and contribution of BIM has been studied, focussing initially on the AEC and subsequently narrowing down into the structural engineering domain. Semi-structured interviews were used to capture the views of customers sampled from two different construction design organisations in the UK. The qualitative interview was structured into two different levels of questions. In the first part of the interview, questions were designed to cover the general area of information management challenges. In the second part, questions were designed in greater detail to find existing supports of BIM that can solve those challenges. This research describes 12 interviews. The results of the qualitative data seek key existing challenges in construction design in companies that used BIM and work in an integrated design environment.

2- Measure: To make decisions and set priorities, this part of the research required ranking the available alternatives and making the appropriate selection. This study derives such weight by conducting a comparison of challenges and BIM supports with respect to their preferences. In this research an open-ended questionnaire was organised to measure the impact of each identified BIM supports to the dimensions of information quality.

3-Analyse: This research applies descriptive statistical analysis to present the ranking of each key information management challenge. To analyse relationships and interactions between an element with other elements, factor analysis and multiple regression are applied. This process identifies the key factors influencing the dimensions of information quality and scores the influence of each factor in comparison with the others.

4- Improve: The process of information management in structural engineering will be improved by presenting an efficient conceptual framework for solutions and alternatives and by implementing an enhanced plan. In this stage the results of literature review and of primary data analysis was compared with each other in order to develop a framework by applying recent BIM tools and addressing the identified challenges by directing identified key contributions of BIM.

4- Control: In the final stage of research process, the conceptual framework is validated through interviewing six BIM experts in industry and academia. The comments of these experts are utilised for controlling clarity and applicability within the industry, and for comprehensiveness and novelty.

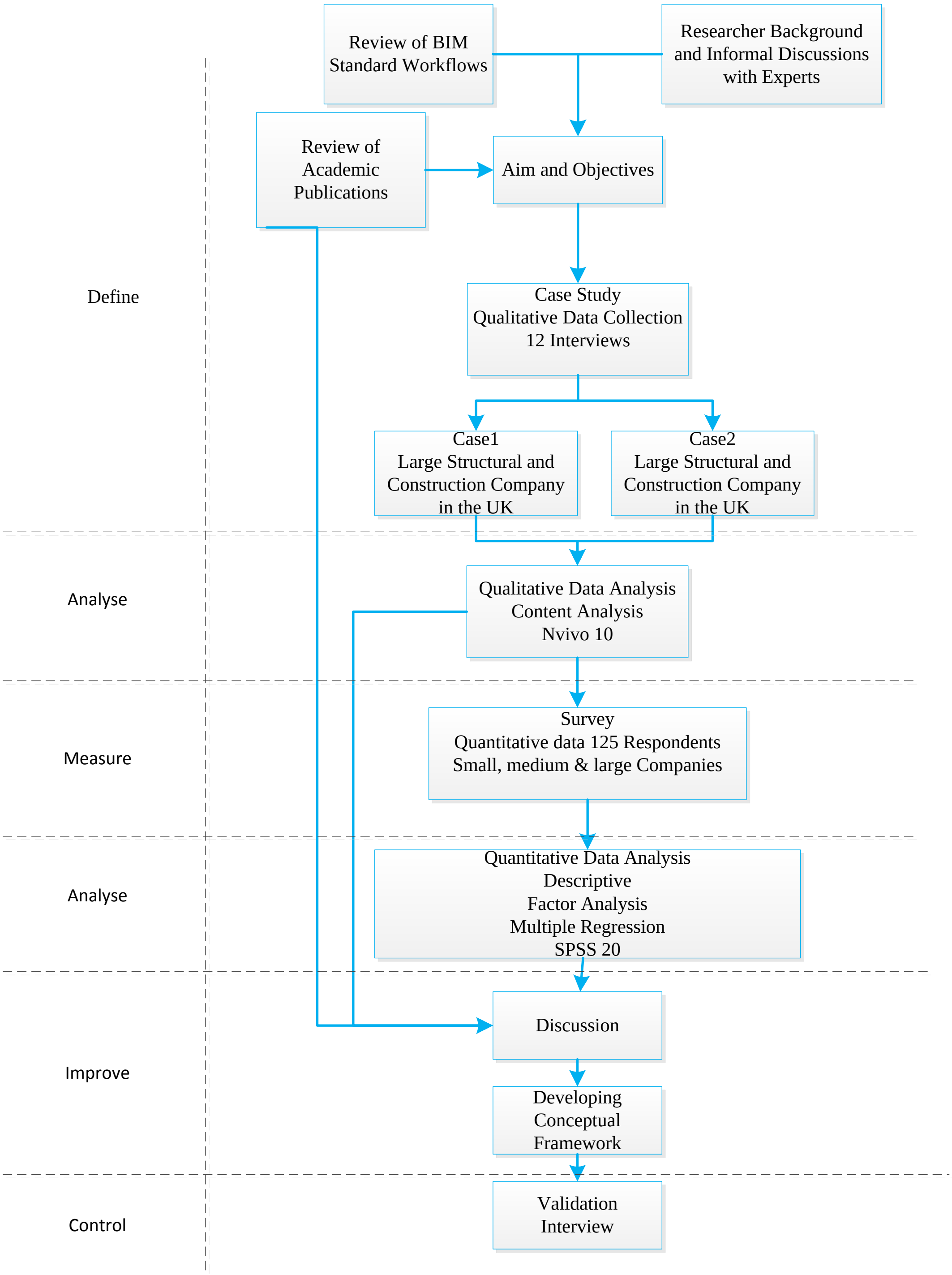


Figure 1-1 Research Approach Design

1.7 Report Structure

This research aims to propose a conceptual framework for information quality to the UK structural design industry. It seeks study the technological capabilities, workflows and organisational human resource readiness in the existing body of knowledge and the process framework. For the purpose of this report, the structure will contain eight chapters as described below.

Chapter 1- Introduction

This chapter provides an introduction and a brief outline of the structure of this report. The research background, research scope, research justifications, research gap, research questions, aim and objectives and expected contribution to knowledge are outlined.

Chapter 2- Review of Information Management in Structural Engineering

This chapter provides an overview of the literature consideration for this research. A general perspective of the structural engineering profession and outlook of information management challenges in AEC with a particular reference to the structural engineering sector in the UK is provided in this chapter.

Chapter 3- Contribution of Building of Information Modelling to Structural Information Management

This chapter provides literature research in respect of contribution of Building Information Modelling (BIM) in information quality management. BIM is studied from technological, process workflows and organisational human resource points of view. The technological dimensions contain: visualisation, file format and standard, structure of data and semantic technologies. The BIM workflows reported on recent protocols that have been provided for the construction sector in the UK. The importance of training and recruitment in the structural industry is discussed in the context of organisational culture and human resources. In the last stage the initial conceptual framework was proposed.

Chapter 4- Research Methodology

This chapter gives an outline for the methodology adopted purposely to achieve the aim and objectives of this research. For the purposes of this thesis, the chapter is a structured based on the research onion model that will present the research philosophies, method, approach, strategies and technique. The section on data analysis presents the processes adopted for both qualitative and quantitative data collection for this research.

Chapter 5- Qualitative Data Analysis

This chapter outlines the structure of qualitative interview questions. This chapter discusses the two case studies that involved information management challenges and the contribution of BIM in addressing the challenges faced by the structural engineering sector in the UK.

Chapter 6- Quantitative Data Analysis

This chapter details the quantitative data analysis and results, where the analysis based on the data collected from structural engineers, design managers and BIM experts. The data collection techniques was principally by conducting a questionnaire survey that obtains the perceptions of the participant with respect to to information management challenges, level of BIM implementation and level of satisfaction of information quality in their organisations.

Chapter 7- Research Discussion

This chapter discussed the key findings of the research that have been achieved from literature review and qualitative and quantitative data analysis. This chapter also provides a framework for BIM implementation in the structural engineering sector to improve upon key information management challenges. Validation of the framework is done by collecting the opinions of industry experts and guidelines for implementing this framework are presented.

Chapter 8- Conclusion

This chapter outlines the conclusion of the research based on research objectives. In addition research limitations and opportunities for further research in this area are also presented in this chapter.

CHAPTER 2. REVIEW OF INFORMATION MANAGEMENT IN STRUCTURAL ENGINEERING SECTOR

The main purpose of this chapter is to review the literature to understand the nature of information management in structural engineering information management in order to identify identifying key information management challenges within the AEC sector and particularly, related to management of structural engineering information. This chapter commences with a general overview of the structural engineering profession. The structural design process, interaction between structural engineering and management information systems, structural engineering information modelling and structural entities, are explained in detail. This chapter collects state of the art literature in the context of information management challenges and opportunities in AEC particularly structural engineering industry, to address objective 1 of this research, as set out in Section 1.4.

2.1 Introduction to Structural Engineering Industry

Structural engineering is defined as a part of the construction design process which utilises knowledge and experiences for analysing force-resistance, designing building or other structures, and document preparation of structures (CASE, 2010). Structural engineers consider factors such as demands of geometry, materials and loads (gravity, wind, seismic, etc) to deal with conditions in which it is built. Structural engineers implement design and analysis processes based on the project requirements and authorisation regulations. Various constraining factors considered by structural engineers include client requirements, environmental consideration, health and safety consideration, live and dead loads, seismic loads, costs, etc. Structural engineers need to identify all aforementioned project requirements to describe their design tasks in conceptual design phase. In performing aforementioned tasks, effective information management plays a critical role. Structural engineering profession is passing through a period of rapid change, with introduction of new digital workflows and automation, which is replacing many tasks traditionally done by structural engineers. This change highlights the need for a better investigation of key information management challenges encountered by Structural Engineering professionals. The next section presents the sequential stages of structural engineering design from past decade to recent years to understand information requirements and transaction in different stages in details.

2.1.1 Structural Engineering Design Process

Structural engineering design process comprises various stages. Manning (1995) categorised the process of structural engineering design into three levels: conceptual, intermediate and detailed. Structural design has been divided into three main subdivisions by Sacks et al. (2000). This is depicted in Figure 2-1: structural scheme design, floor layout design, and functional system design. In the structural scheme design phase, the clients' requirements as acquired by architect are passed on to structural engineers, the site data is clarified and subsequently, the building's shape, height, position and the number of floors are proposed. The Floor layout design phase covers the layout of all the building spaces and assemblies of their components. Finally, in the functional system design, the details and dimensions of objects are calculated and added into drawings.

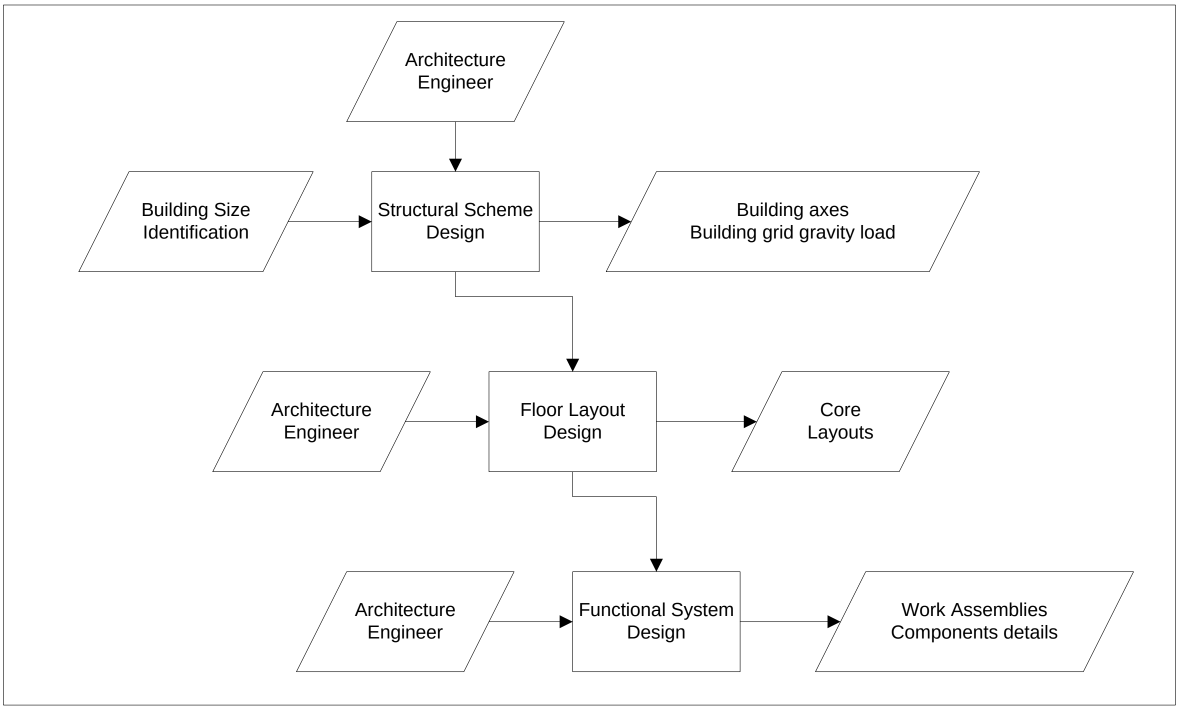


Figure 2-1 the sub-stages of structural engineering design (Sacks et al., 2000)

On the other hand the RIBA (Royal Institute of British Architects) (RIBA POW, 2013) organises the construction design process into concept design, developed design and technical design (See Table 2-1). RIBA POW (2013) is one of the most commonly used process structure on design in the AEC industry in UK. It specifies information requirements at different project stages. Collectively, the plan of work and associated guidance and tools provide a good framework for collaboration on construction projects. The scope of the various stages of the process has been described by the RIBA POW (2013). Proposals for structural design and building services system are outlined in the concept design stage. In addition, cost information and project strategies would be specified briefly in accordance with the design programme. The developed design consists of updated and coordinated proposals for structural design, building systems, cost information and project strategies. In technical design phase, the Design Responsibility Matrix and project strategies are prepared for all architectural, structural and building services information. Table 2-1 illustrates tasks required for each stage, which may overlap in some stages, to enable achievement of specific project requirements.

Table 2-1 RIBA Plan of Work

RIBA 2013	**Conceptual Design**	**Developed Design**	**Technical Design**
Objectives	• Structural outline proposal • Building Services outlines • Cost and strategies briefly	• Structural updated • Building services updated • Cost and strategy updated	• Responsibility Matrix • Architectural details • Structural Details • Building Services
Procurement	The procurement strategy does not alter the progression of the design; however, information exchanges will vary depending on the selected procurement strategy.		
Programme	Review project programme	Set up the specific stage dates and detailed duration	
Planning	A bespoke RIBA plan of work 2013 will identify when the planning application is to be made.		
	• Prepare sustainability strategy, risk assessment, project	• Review and update sustainability	• Review and update sustainability

Support Tasks	execution plan and construction strategy. • Develop health & safety plan. • Undertake research and development party.	strategy. • Review and update Project Execution Plan, including Change Control Procedures.	strategy. • Prepare and submit building regulations. • Review and update project execution. • Review construction strategy and health and safety strategy.
Sustainability Checkpoints	Sustainability Checkpoint 2	Sustainability Checkpoint 3	Sustainability Checkpoint 4
Information Exchanges	Concept Design including outline structural and building services design, associated Project Strategies, preliminary Cost Information and Final Project Brief	Developed Design, including the coordinated architectural, structural and building services design and updated Cost Information.	Completed Technical Design of the project.

The different structural engineering design frameworks have been presented up to now to clarify structural the design process. Team members add information in each stage of design process. The management of information flow between team members is very critical for project progress. In the context of information flow management there are some basic concepts and supportive tools that should be considered. Information management systems support the day to day routine engineering activities to document structural engineering information in each level of conceptual, developed and detailed design stages. In the next section the connection between different layers of information system with structural engineering information flow are discussed.

2.1.2 Structural Engineering Information System

Information systems play a crucial role in the administration of day-to-day business. The ability of organisational business services exceedingly depends on the capability of its information systems. An information system consist of data, information and processes to store and distribute information to support decision making in an organisation (Laudon and Laudon, 2012). A typical organisation such as a structural engineering company requires information systems for each of the major engineering and business functions. The engineering functions need systems to support engineering design and analysis, and procedures to document the information concerning structural components. Therefore, it is worth to consider the recent models of information system.

In organisations, information systems serve to support different groups of management requirements. It has been argued by Laudon and Laudon (2012) that for each level of management group in an organisation, different information systems need to be described. Engineer’s operational level requires systems to keep track of the elementary activities and transactions. The transaction processing system (TPS) performs and records the daily routine transactions to conduct structural information requirement and capturing, structural analysis and design activities transactions, and documentation of product outputs. Middle management level requires a system to aid with monitoring, controlling, decision-making and administrative activities. Management Information System (MIS) is a system to help middle management to monitor the reports and analysis of information which are produced in the transaction processing system. Figure 2-2 illustrates that in structural engineering organisations, the middle management comprises of design managers, who are responsible for monitoring and controlling the engineering transaction processing system. This level of design management often requires displays and dashboards to control the lifecycle of product information management.

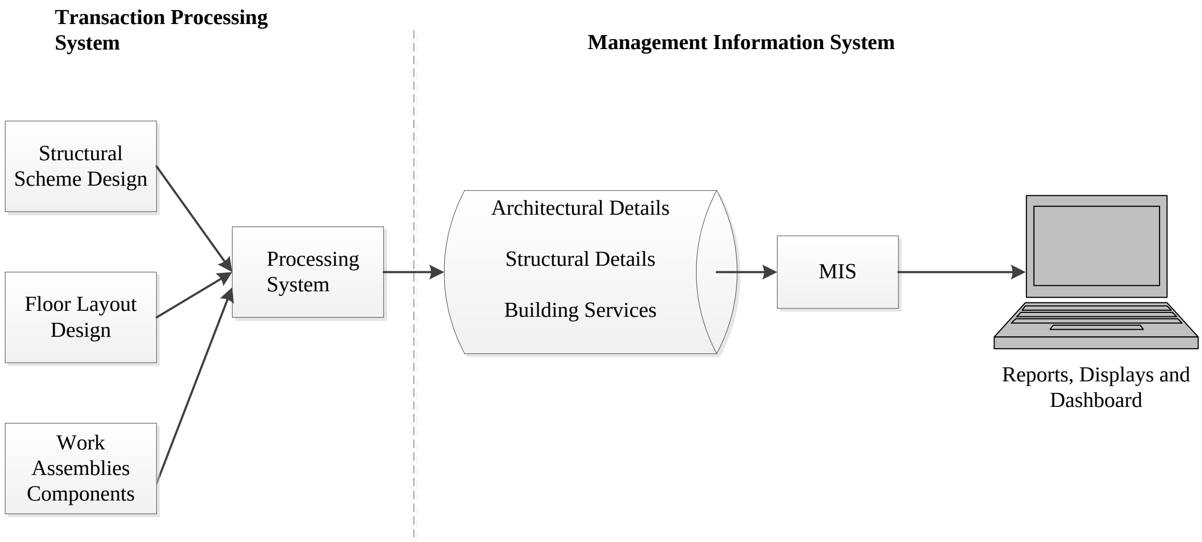


Figure 2-2 Structural Engineering Processes Information System Management (by author)

Two different methods of design process can be applied by structural engineering organisations and these include the point based and the set based systems. In the point-based system, a single option of feasible design will be selected based on designer's experience and subsequently that design will be modified by more information (Lee et al., 2012). In the set-based design, various design alternatives are considered by specific stakeholders at the same time and the information can be transferred about the set type alternatives. The main difference between set-based and point-based design is presented in the Figure 2-3. Set-based design maintains more alternatives than point-based. When compared to the point-based method, the set-based design is more efficient in the integrated design environment. By using set-based method, designers can produce and analyse alternative solutions faster, in comparison with when done separately (Parrish, 2009, Bavafa et al., 2012).

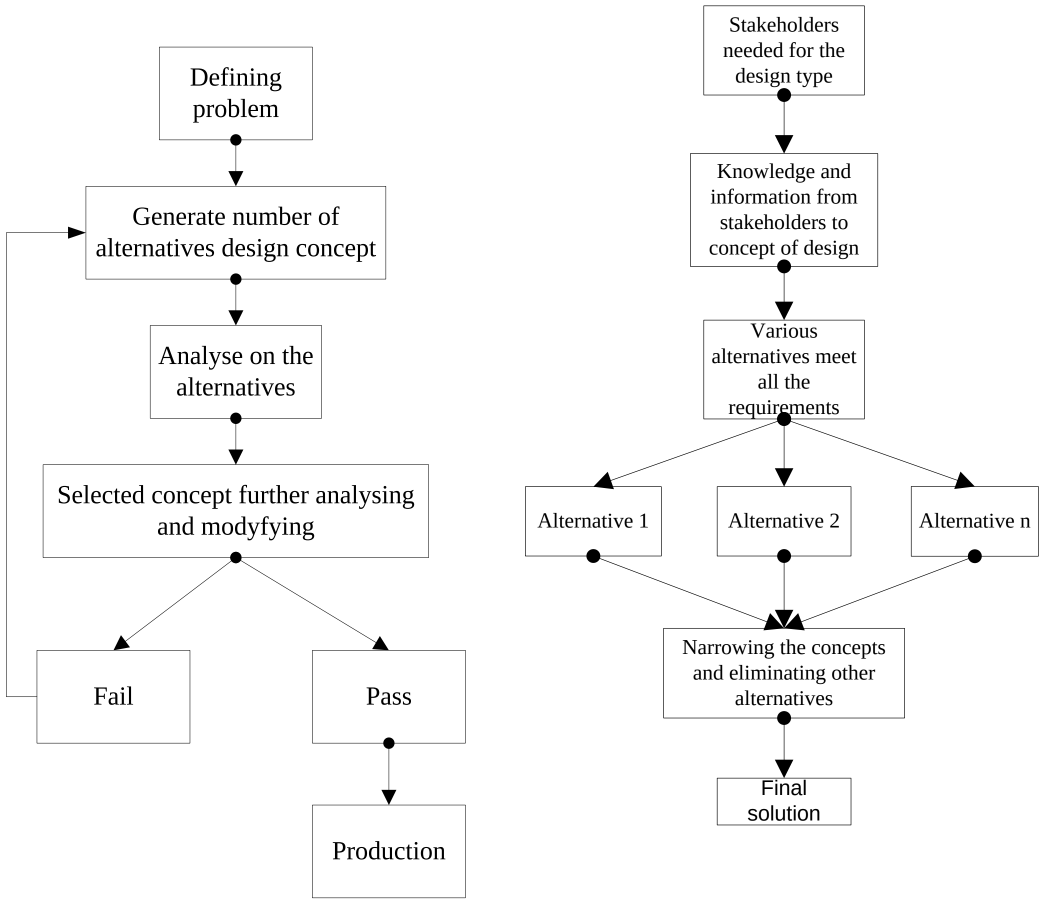


Figure 2-3 Point-based design b) Set-based design from Bavafa et al (2012)

Figure 2-4 is indicated that structural engineers in TPS sector of information system meet all the design requirements and design alternatives from their internal design team or external stakeholders such as architects and clients in initial phase of design. Despite the traditional structural engineering process, they do not use trial and error system. Both design managers and structural engineers in the set-based structural information system accesses to cost strategies and sustainability strategies in parallel with architectural, structural and building services details which would help take efficient decision in the narrowing down the alternatives phase.

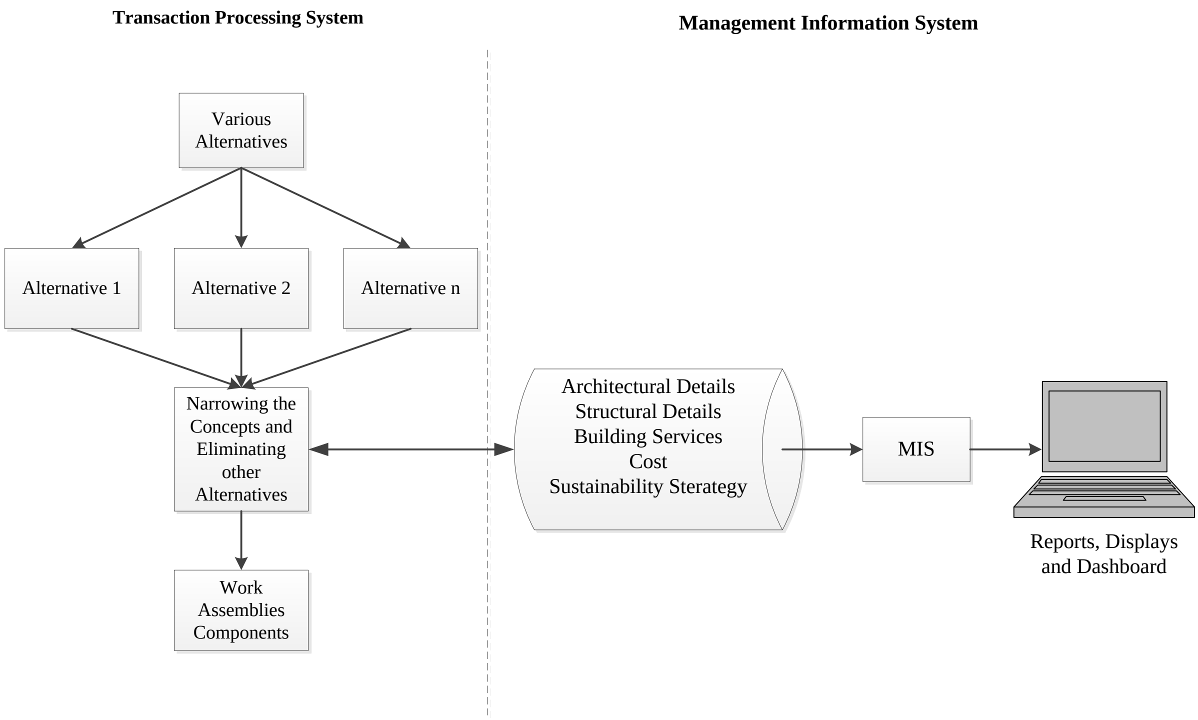


Figure 2-4 Set-based Structural Engineering information Management System (by author)

In this section it was pointed out that the integrated design environment has altered the traditional method of information system management. By using Building Information Modelling based information systems, it is possible to integrate physical data about a facility (e.g. beams, columns and other components that are part of physical representation) and analytical information (i.e. model used for structural analysis) Being able to pull relevant information from integrated databases, offer structural engineers new possibilities to effectively manage design. Moreover, structural engineers need to model their information through information system. This procedure involves inputs from many sources, such as technical experts, architects and structural engineers. Inputting data still consists of carrying out collection, collation and management by translating from internal system to a database or vice versa. This section clarifies the differences between traditional information system in structural engineering and set-based information system. This research is concentrated on set-based structural engineering information system which can work more efficiently in integrated design environment instead of point-based design system. The next section explains the information modelling definition by structural engineering.

2.1.3 Structural Engineering Information Modelling

Calculation and quantity take off are the fundamental parts of structural engineering discipline. Structural analysis and design are very complex processes and cannot be performed manually. Therefore, there is a long history of adopting computers in structural firms to develop digital information. Although structural analysis and design calculations are very advanced and are developed by state of art computer solutions, information modelling in the context of structural engineering is very isolated and different from other disciplines (Wyatt, 2012). Structural analysis and design can be started after receiving architectural drawings by tradition. Structural engineers start to simulate geometry model of building according to architectural drawings and create a structural calculation model. Accurate understanding of the requirements of the client and architect is a significant consideration for structural engineers. Traditionally, the architectural package provided to structural engineers suggest the size of structural elements (beams, columns, slabs, walls, etc.), position of structural elements, openings in walls and floors and material types; however, it is for the structural engineers to finalise the exact details of these elements based upon their calculations. Recently, integrated building design environment encourage structural engineers to be involved not merely in calculation and providing stiffness and durability of elements but also structural engineers can cooperate with contractors and other design disciplines in early stage of building lifecycle to provide their technical information regarding to sustainability and installation procedures. During the design phase, structural engineering modelling is divided in to three categories which include data modelling, product modelling and activity modelling. In the structural design process (Ford et al., 1995), there are some data such as codes and methods of design that cannot be modelled through product visualisation or graphical standards. These are categorised into data modelling. In the course of product modelling, the structural components and relationships between components will be modelled. Through activity modelling, the construction process is simplified and made to order.

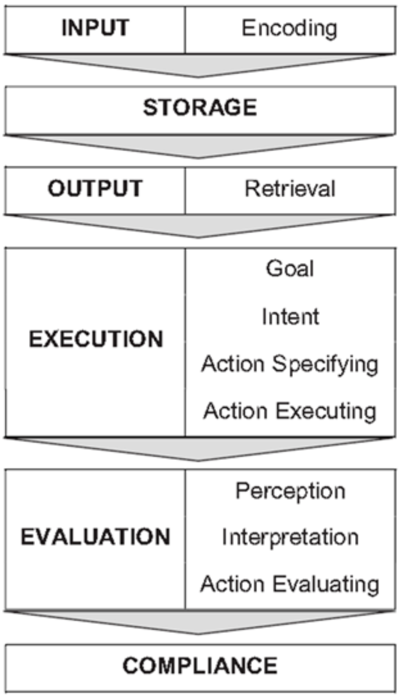


Figure 2-5 Stage of the action cycle (Lopez et al., 2010)

As it is shown in Figure 2-5, all these modelling types involve three main levels of computer system procedures, including input, storage, and output. After outputting models, and before delivering them to contractors, a company is required to evaluate models through project expert disciplines, in order to reduce errors and risks (Lopez et al., 2010). This research considers all three main information modelling procedures as components of information management in structural engineering disciplines. This section sought to obtain more understanding of information modelling procedures before studying challenges among information management context. There is also the intention to understand the main and other entities involved within structural information management in exception of structural engineering discipline. Therefore, the next section explains external entities who are affecting structural information management.

2.1.4 Structural Engineering Entities

The importance of data storage in construction organisations cannot be overlooked, and to ensure that the data is readily retrievable it has to be classified into different functional groups during storage. With this aim, the environment has been categorised into three entities (Ford et al., 1995); the first entity is called *tangible*, which stores information about physical objects (e.g. a surveyor site), the second entity is *conceptual*, which stores data about less tangible objects of interest to the construction industry (e.g. legal constraints), and the third entity is called *active*, which is used to capture and store events that have taken place (e.g. soil analysis entity). Scherer and Schapke (2011) interpret the domain of storing and the co-operation of information in structural designing entities from another point of view; they represented the "multi-model" as a container of data to combine distributed applications and models. The domain of the multi-model categorised by Scherer and Schapke (2011) has four layers:

- Level 1 - Processes for planning, executing and controlling a project
- Level 2 - Functional, geometrical and topological information of building elements
- Level 3 - Construction economic and co-ordination model
- Level 4 - Construction uncertainty and risk models

Level 1 of the building information domains provides the models of comprising the activities with schedules and utilising the construction project information in parallel to the material procedures. In level 2, all of the elements are modelled with their basic geometrical and mechanical characteristics and, in this level of modelling, Industry Foundation Classes (IFC) can be utilised to enable the physical building element's information and topology exchange. Level 3 of the building information domains represent the quantity take off and prices of building elements, human power and all other costs. Finally, level 4 contains construction uncertainties and risks; this model might be utilised to evaluate design and management decisions.

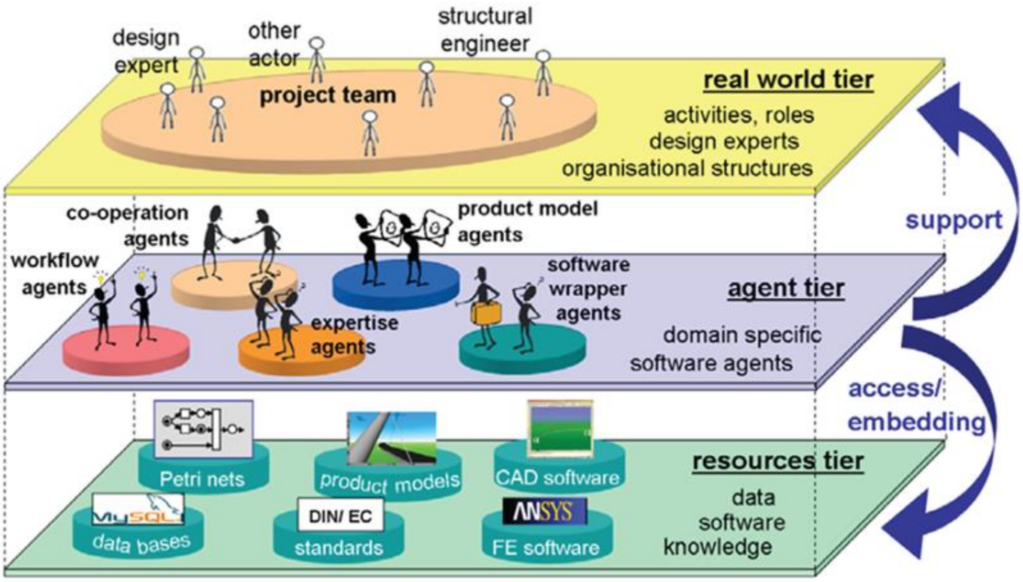


Figure 2-6 Three-tier model for collaborative structural design (Bilek and Hartmann, 2006)

The cooperation between structural engineers and other experts has been modelled in greater detail by Bilek and Hartmann (2006) and is depicted in Figure 2-6. In this model, collaborative entities that co-operate with structural engineering companies have been categorised into three tiers: the first tier is the real world, which involves the construction project, such as designers or other key participants; the second tier is the agent tier, who develops software and IT supporter entities; and the third tier is the resources tier, including database, software and knowledge that the real world and agent tiers could access for co-operation and to implement their works. As it has argued by Al-Ghassani (2003) the key challenges in structural engineering organisations refers to information intensive tasks. The information in structural engineering organisations is captured in various forms which named "different types of knowledge" by Al-Ghassani (2003) And structural designers uses various applications to model their graphical information and document the non-graphical information. Therefore the efficient information management strategy has a critical role in the information intensive structural engineering profession. This section contributes to structural engineering information management trough understanding of information technology resources and information technology supporters. Therefore, for identifying key challenges this research narrowed down its concentration on interactions between all those three aspects; technology, process and human resources readiness. This research In the next section the information management challenges within AEC industry and particularly in structural engineering industry are reviewed.

2.2 Key Information Management Challenges in Structural Engineering

Traditionally, information management among various AEC disciplines was based upon 2D drawings. In the 1960's dramatic changes in the nature of drawings of buildings and drafting by structural engineers were brought about by computer-based graphic systems (E.Weisberg, 2008). Prior to the introduction of BIM, the detailed design phases in structural engineering were facilitated by CAD (Computer Aided Design) software, but it was felt that the building information was not efficiently documented as it was appreciated by the industry that building information was more than a simple geometric shape (Eastman, 1975). Therefore the demand for information sharing between diverse disciplines of the AEC industry and the need for availability and accuracy of information in the early stages of the design process encouraged the industry to adopt BIM. Recently, structural engineers are facing external pressure to adopt BIM-based software which enables them to exchange information with architects and contractors (Lea, 2013). Detailed literature related to information management challenges right from the broad perspective of the AEC industry, narrowing down to the structural overview have been provided in this section and the following chapter dwells upon the BIM solutions for identified information management challenges.

To be able to comprehend the various aspects of information management, it is imperative to understand the differences between data, information and knowledge. In this regard the literature abounds with definitions of data, information and knowledge. It is commonly accepted that data comprises of raw numbers or facts, information is that data that has been processed and knowledge is information which is authenticated (Vance, 1997), Therefore, data, information and knowledge are parts of a sequential order. Zins (2007) argued that information management science should be excluded from knowledge management as these two aspects are entirely different.

Within AEC organisations differences between information and knowledge would be distinguished in terms of context, usefulness and interoperability (Venters, 2009). Conversely, Venter's opinion has not been accepted by many, and it has been argued that the distinction of information and knowledge is not referred to context, usefulness or interoperability, and knowledge is the type of information which is processed in the individual's mind. Information is categorised into two discourses; human discourse system and computational system. In human discourse information is defined as meaning of assertion however, in computational system its included digital information which can be retrieved in databases (Baskarada and Koronios, 2013).

Information comprises of interpretations of data and the contextual understanding of product. In most instances the decision making process in organisations is based upon the information that individuals can capture, access and communicate with each other (Coakes, 2003). Information management is the process that supports the lifecycle of creation information, representation of information, maintenance of information through to reprocess the information. Many organisations view efficient information management as a competitive advantage. In view of this efficient information management can support technologies with business process improvement in organisations. Therefore a comprehensive method to information management requires strategies, tools and processes to manage information through lifecycle.in this section, this research collected the state of the art literature in the context of information management challenges and opportunities in AEC particularly structural engineering industry.

Data, information and knowledge in AEC can be identified in the lifecycle of capture, use, edit, exchange and reuse. However, The AEC industry is limited in terms of understanding of the details of data, information and knowledge. Early literature was interested in the different definitions for data, information and knowledge (Beijerse, 1999, Kakabadse et al., 2003). However, AEC organisations require a mix of data, information and knowledge. The organisations (e.g. AEC) have adapted to different methods to manage the lifecycle of information and knowledge management: The information technology tools and strategies focuses on information technologies to facilitate information and knowledge management lifecycle (Earl, 2001). Comprehensive information management does not result from the implementation of IT solutions alone, organisational and process issues should be taken in consideration in parallel with technology consideration (Shelbourn et al., 2007). The information technology tools are frequently labelled in electronic databases and collaborative tools to enable information sharing moreover, the establishment of efficient strategy is needed to motivate and enable information system users within organisations to achieve organisational goals. Table 2-2 has presented the summary of literature review which discussed the challenges in information management among AEC industry.

Table 2-2 Information management challenges in AEC industry

Information management Problem in AEC	Author	Discussion
Inefficient Collaboration	(Shelbourn et al., 2007)	Good collaboration does not result from the implementation of IT solutions alone. Focus on organisation and process issue is required in parallel with technology consideration.
	(Froese et al., 2007)	The most regularly identified problem in Canadian construction refers to collaboration including communications, document management, and interoperability.
	(Shen et al., 2010)	Lack of a systematic theoretical framework for communication in construction organisations.
	(Gassel et al., 2014)	Weak willingness to share information and knowledge with others.
	(Fulford and Standing, 2014)	The problem today is that the building object is a combination of design results, because the collaborative working is not well organized or well managed as a result of a lack of insight into relevant process variables. The construction industry lacks the 'strength' of relationships to generate a network of organisations which trust and have shared values process and information need to be standardised.

	(Egan, 2002, Jardim-Goncalves et al., 2006, Grilo and Jardim-Goncalves, 2010, Shen et al., 2010, Shen et al., 2013)	Information interoperability
	(Li et al., 2015)	AEC organisational information efficiency and communication
Distributed information access	(Rezgui et al., 2010)	Information accessibility
	(Sheriff, 2011)	Incoherent in the application of metadata and the attributes.
	(Rob et al., 2012)	The significant value of accessibility, accuracy and currency of the information relating to the project.
	(Zlatanova et al., 2012)	validity of objects may not be ensured
	(Gorla et al., 2010)	Four dimensions of information quality: accuracy, completeness, consistency, and currency (Emphasized on information quality, the quality of information outputs that be valuable for business users and relevant for decision making)

	(Li and He, 2013)	Exchange and sharing information between different participants and different applications. At present, BIM is considered to be an effective way.
	(Corry et al., 2014a)	Improving information interoperability and accessible sourcing leads building performances.
Inefficient ICT technology adoption	(Vidogah and Moreton, 2003)	Due to cultural and legal reasons, there is no desire to consider collaborative IT tools.
	(Peansupap, 2005)	Lack of understanding of how to actually implement ICT into a construction organisation.
	(Peansupap and Walker, 2005a)	Lack of time to learn the new information and communication technologies in organisation.
	(Sheriff, 2011)	The nuisance in preparing people to change their ways of working and adopt new methods. And lack of professionals with the requisite skills.
	(Morlhon et al., 2014)	Maturity and critical success factors of ICT should be evaluated to implementation.

The main focus of the existing body of knowledge related to information management in the AEC industry is premised on three main categories; firstly, capable collaboration and co-ordination between multiple disciplines (Anumba et al., 2004, Peansupap and Walker, 2005a, Yeomans et al., 2006, Shen et al., 2013, Li et al., 2015); secondly, fragmented information and insufficient access to data and information (Gorla et al., 2010, Sheriff, 2011, Rob et al., 2012, Corry et al., 2014a) and thirdly, inefficient ICT facilitating and adoption in AEC industry (Vidogah and Moreton, 2003, Peansupap and Walker, 2005b, Sheriff, 2011, Morlhon et al., 2014).

Increasing complexity in the AEC industry require professional designers and construction experts from multi-disciplinary professions to communicate with each other, understand the communications context ,document the result of the communication and access to document in requested time. The communication may be inter-organisational or external communication with other disciplines. In both type of communication, organisational culture and business strategy have been identified as two critical success factors (Xue et al., 2010).

Successful industry information management is yet to be achieved as there are several barriers that prevent widespread adoption of information technology in the AEC industry. This is despite the fact that in addition to organisational and business strategies, in the past few decades the AEC market has seen a proliferation of digital tools that contribute to collaboration in the industry (Azhar and Ahmad, 2015). Although the adoption of technology in construction information management, especially in the design and management processes has the potential for great improvement and change among organisations, there are some challenges that preclude successful adoption and utilisation of recent technologies. A wide range of barriers in the adoption of information and communication technology in the AEC industry have been discussed in the literature.

Robinson et al. (2001) examined information management challenges in United Kingdom engineering and construction organisation as: to share valued tacit knowledge, to rapid reply to customers, to circulate best practices and to reduce rework. Peansupap and Walker (2006) examined the barriers in the Australia construction industry in adoption of information technologies. They argued that barriers could be classified as individual, group and organisation levels. At the individual level there was limited budget for information technology investment; there was issue with information management technology standardisation and security problem. At the group level there was lack of personal contact due to geographical fragmented parties. And At the organisational level there was lack of time to learn the new information technologies applications.

In the context of organisational culture; trust, tension, conflict and incentive are identified as four organisational culture factors which impact the performance of communication in construction projects (Xue et al., 2010). Moreover business strategy play significant role in enhancing communication performance within AEC industry. The technology has advanced more quickly than the business process model, therefore the productivity improvement of efforts in business strategy are highlighted as important factor rather than development of new technologies (Helin and Lehtonen, 2007).

In the AEC industry, information management can be considered under various themes such as: **Organisational culture level**, **Business process strategy level** and **Technological level in the market**. It has been found from the review of literature that there is a lack of readiness of the AEC industry to adopt technologies to extensively improve information management and communication (Azhar and Ahmad, 2015). Fragmented applications and a heterogeneous information management environment lead to a lack of availability of the information (Eastman et al., 2011). The scholars attention in AEC information management has been turn on by Dossick and Neff (2011) into “messy talk” communication interactions in AEC industry. For the AEC industry to capture the information and then to process it into knowledge by understanding the content, and subsequently to document it for access, or to deliver to other disciplines, however, it is associated with a lack of organised interoperability which has been mentioned in the literature review. Due to time and cost limitations, this research will not cover all disciplines of the AEC industry, and will be limited to the context of the state of the art in information management in the structural engineering sector, an area which has so far been neglected in the existing literature.

Challenges faced by AEC information management have been studied extensively, but requisite attention has not been paid to the challenges associated with information management in the structural engineering sector. Importantly, the distinction between the two has to be made. AEC is an information intensive and fragmented industry, whereas, structural engineering is a part of the engineering design phase of construction stage in the lifecycle of the project. Recent development of computers and information technology has brought about a distinction between the information of physical structures and the information of design process.

This is in turn is responsible for changing the ways of fragmented structural design into integrated design. In the context of structural information management, some authors (Sacks and Barak, 2007, Mora et al., 2008) asserted that challenges and communication technologies in structural engineering increasing dramatically, uncertainties in structural engineering information management. Demoly and Yan (2011) argued that structural designers require to access to assembly information even at the very early design phase and thus enable structural designers to make more efficient decision. Aagaard and Pedersen (2013) emphasised on lack of control on design information in structural engineering information management system. Goupil (2007) examined from group discussion between several structural engineers that the main challenges for structural information management is reducing errors in design by considering hazardous and implementing BIM to increase their collaboration with other construction and design disciplines. Lee et al. (2012) also focused on high-rise building structures and their research emphasised on optimised structural information to reduce errors and reworks that frequently occur in non-integrated structural information management. From the existing literature review it reveals that the most key challenge for structural engineering discipline are related to achieving minimum hazardous and structure failure by delivering accurate information to fabricators and contractors. And also communication and information exchange which are related to interoperability are structural engineers issue. Access and control on information also emphasized as a key challenge in structural engineering sector. It has been also argued by Chandrasegaran et al. (2013) in recent information management environment in building design sector that raw information is available to designers however, the critical challenge is presenting information and transfer information among design teams.

This research consequently by reviewing most of the concerns in state of the art literature related to AEC information management challenges, construction design information management challenges and structural engineering information management challenges predicted that most key challenges in structural engineering information management challenges are refers to information quality. This research stresses that by enhancing the level of certainty of information in structural engineering organisations, the quality of structural information needs to be considered.

2.2.1 Information Quality Management

Several researches signify that between 50% to 60% of changes during construction projects take place due to poor quality of information design (Kirby et al., 1988). Review of the literature data and information science has revealed several dimensions of information quality. Information quality dimensions are very broad as a general subject in organisations. Pipino et al. (2002) measured stakeholder perceptions of information quality in healthcare, finance and bank firms and listed its dimensions including; accessibility, appropriate amount of data, believability, completeness, concise representation, consistent representation, ease of manipulation, free of error, interoperability, objectivity, relevancy, reputation, security, timeliness, understand-ability and value-added. The main four dimensions of information has been investigated in model-sound, dependent, useful and usable (Kahn et al., 2002). Further, Kahn et al (2002) provided benchmarking for evaluating method of providing information and delivering dependent and usable information to consumers. Yang et al. (2005) highlighted five dimensions of quality for evaluating web information including; accuracy, accessibility, usability, usefulness and interaction.

An understanding of the quality of information is essential to comprehend its role in information management in the field of construction engineering .It has been pointed out that information quality plays a crucial role in construction engineering, and especially in the design phase, poor information quality leads to poor drawings (Westin and Sein, 2013). There are several dimensions for benchmarking the quality of information. Most of the scholars in AEC industry focused on three main information quality including accessibility, accuracy and interoperability. The dimensions of poor quality information have been highlighted (Marshal, 2004) which is inaccurate, incomplete and inaccessible. In addition Marshal (2004) believed that organisations require strategic information management system based on those core factors to improve information quality. Moreover, Gorla et al. (2010) highlighted the dimensions of information quality as information accuracy, and information accessibility and information interoperability. Curry et al. (2013) highlighted accessibility and interoperability are key criteria in order to manage information in AEC industry. It is vital to access to different source of information. Interoperability is a main challenge in information interaction between sources. The benchmarking of information quality depends on the use of the information and what is recognised as poor information in one case may not be applicable in another case.

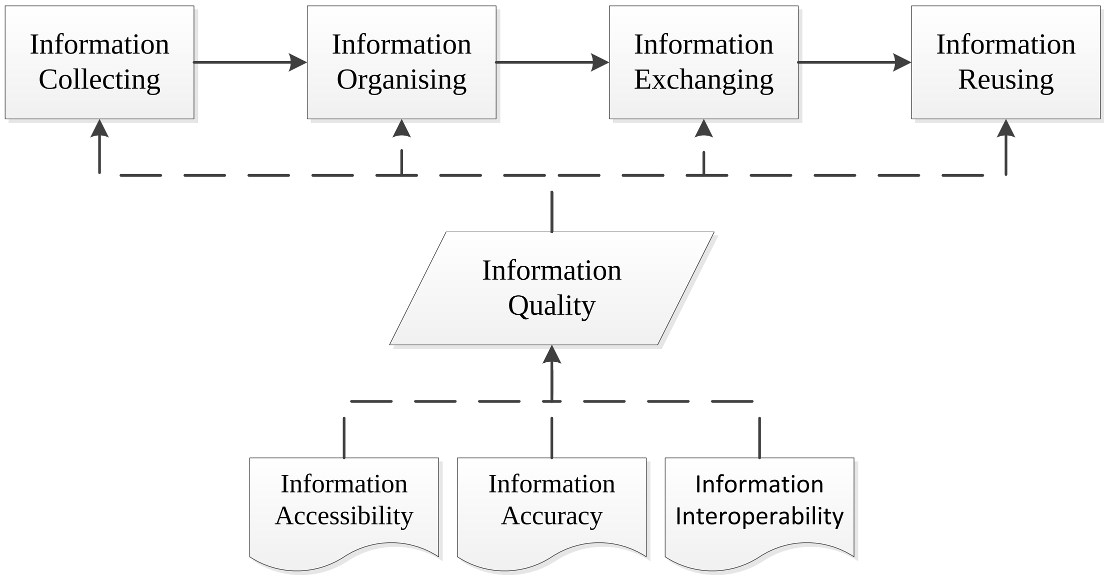


Figure 2-7 Information quality impact on information lifecycle in Structural Engineering

Figure 2-7 shows that information quality has a significant influence in the entire information lifecycle (Information collection, information organising, information exchanging and information reusing) in structural engineering information management. The three main dimensions of information quality consist of: Information accessibility, information accuracy and information interoperability. this research attempts to obtain the expert overview for validation of these dimensions. In the following sub-sections each information quality dimension in the context of structural engineering disciplines is described in details.

2.2.1.1 Information Accessibility

Information retrieval is a well-establish research in engineering information management area. Information access in engineering sector has been surveyed by Liu et al. (2008) essentially to improve information management performance within AEC industry. A number of researches argued that engineers spend two-third of their time due to obtain output results from their work and they spend one-third of their time on searching and accessing to design information (McMahon et al., 2004, Hertzum and Pejtersen, 2000). It is very vital in engineering product design area that information be organised and structured for efficient retrieval (Chandrasegaran et al., 2013).

Accessibility in the collection of information is an essential requirement in structural engineering information management. Structural engineers usually have distinct information requirements. This information consists of unstructured data, semi-structured data and structured data set in relational data warehouse. The availability of information are not efficient in AEC industry due to vast volumes and complex information (Lyman and Varian, 2010). The fundamental function is to select the most useful information in the requested time frame. This underscores the importance of classification of information in information accessibility, especially when the organisation has to handle large volumes of information (Dash and Lin, 2003).

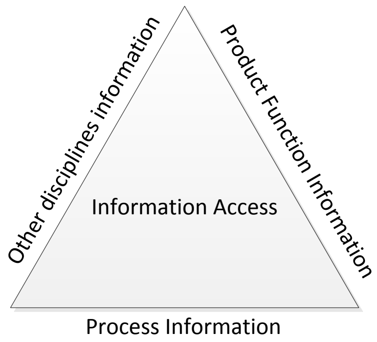


Figure 2-8 Information Access Dimensions

Reviewing the state of the art literature shows that there are three information categories which are vital to be accessible in structural engineering design sector (See Figure 2-8). The first category is the raw information which may be collected from various sources for example; architect, client, local authorities and building services. Structural engineers can be consumers of some sort of information or producer of other sort of information (Sacks et al., 2000). The second category is related to information of predicting behaviour of product. Chandrasegaran et al. (2013) argued that to design physical engineering structure mapping between function and structure is often a critical challenge. Sometimes behavioural functions of certain structures are not predicted accurately due to lack of sufficient access to product functional information. The information has to be recorded and updated regularly to enable decision making in the analysis and design phases.

Information representation is very vital for structural engineering information management system and behaviour function prediction of structure products should be accessible and presented well by system to designers to make accurate decisions. And finally the third category is the structural process information. Engineering processes are very information and knowledge intensive process (Liu and Young, 2004). At the end of structural engineering process, there is extensive information accumulated that would be potentially be utilised in upcoming projects (Liu et al., 2008).

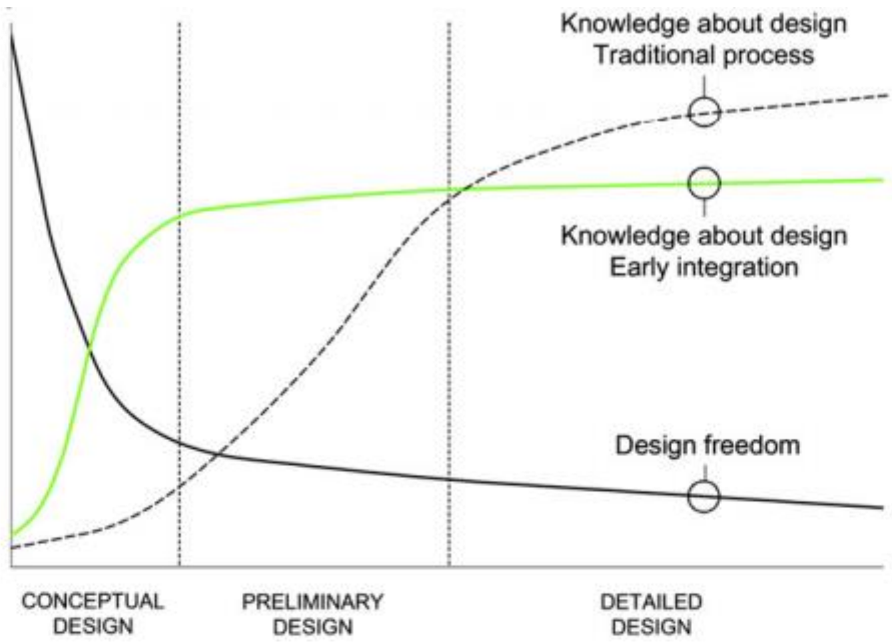


Figure 2-9 Knowledge availability in structural engineering processes (Caviers et al., 2011)

In future projects structural engineers will access to information related to previous projects in early of stage design while this information can be documented in efficient way. Caviers et al. (2011) called this approach of information management as early integrated approach. The graph in Figure 2-9 presents the relationship between available volumes of knowledge in each phase of structural engineering design in a traditional integration method in contrast with an early integration method. As it can be seen in this graph in traditional information management system the available knowledge in early conceptual design stage is very low and it's gradually increase towards detailed design. On the other hand, in early integration information management system most of the knowledge can be retrieved at the early conceptual design stage.

2.2.2 Information Accuracy

Inaccurate information in engineering design leads poor performance and poor productivity in construction industry (Love et al., 2008a). In general, design information are not accurate and available when a construction project goes to tender. Thus it causes projects run over time and budget (Barrett and Barrett, 2005). At present there is substantial pressure on engineering designers due to demands of lower error and faster time of information delivery to manufacturing or construction sector (Chandrasegaran et al., 2013).

As information stored in databases forms the input to other applications, information accuracy is thus very important for achieving organisational goals. Inaccurate information may result from various causes. For instance, certain information values may be missing as they were not available during the period of recording and transacting. The accuracy of project implementation by the contractor and subcontractor depends upon the information provided by design documentation (Love et al., 2000). Therefore, accuracy of documentation is critical for success of the construction project. 2D and 3D generated drawings specify the physical structure. In addition to this fact, the process of construction and installation may be presented in structural engineering documents. As a result it may improve conflicting, incomplete and erroneous information for passing to contractor's requirements.

Figure 2-10 Sheffield building collapse blamed on digger (BBC, 2013)

There are two aspects that cause errors in design: the first is human error, which is caused by insufficient knowledge, ability and skills of designers (Minato, 2003), and the second aspect is the insufficient system design, which impacts on the engineering documents' accuracy (Love et al., 2008b). When Computer-Aided Design (CAD) was implemented in AEC organisations, they reduced their expert designers (Hoxley, 2000). People who are involved in information lifecycle in organisations have the most potential to minimise errors. Lopez et al. (2010) classified design errors into people, organisations and project strategy. Inaccurate information in structural engineering design may contain incorrect calculations according to building codes and Euro standards, wrong dimensions of structural components and incorrect references to drawings. Love et al. (2013) identified seven classifications error types in construction design documents including the following;

1- Incorrect labelling (when names of structural components are ladled wrongly)

2- Drawing omission (when structural elements or some elements of structural components were missed from drawings)

3- Inconsistent labelling (when names of same structural components are not identical among different drawings)

4- Incorrect connection (when connections between structural elements were not design adequately)

5- Incomplete information (when information among drawings and reports are not sufficient for construction purposes or client and local authority's control)

6- Wrong design (when structural elements were not meant to design on a certain drawing)

7- Missing labels (when structural elements are drawn however are not labelled in drawings)

This sub-section described the different views in the context of information accuracy in structural engineering disciplines. This research utilised mixture of those views to describe the meaning of information accuracy in this research. Therefore, information accuracy in this research means the lack of errors (in terms of drawings and calculations), completeness of information (to be sufficient for clients, local authorities and contractors) and constructability of information according to constructors' capabilities and project's requirements. The next sub-section describes the information interoperability as third main dimension of information quality.

2.2.3 Information Interoperability

The significance of information interoperability has been underscored by a report published by the National Institute of Standards and Technology (NIST) (Gallaher et al., 2004) which has estimated a loss of $15.8 billion in 2002 resulting from inadequate interoperability within computer-aided engineering systems. In the past few decades, several reports and researches have highlighted the need for interoperability and collaboration in the AEC industry (Latham, 1994, Levene, 1995, Egan, 2002, Grilo and Jardim-Goncalves, 2010). The US National Institute of Standards and Technology (NIST) published a report, The meaning of interoperability was argued by Khemlani (2004) describes interoperability as how to "integrate the various model-based applications into a smooth and efficient workflow". IEEE

(1990) defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged".

This dialogue has identified that interoperability is categorised into two processes: 1- The interaction between systems and 2- The applicable usage of exchanged data into other systems. There are different forms of interaction between systems or participants: collaboration, coordination and communication. As presented in Figure 9, communication is the underlying part of information interaction and covers the exchange of information from the sender to receiver component via channels and collaborations. In the coordination layer activities are aligned in order to manage scheduling and dependencies.

Interoperability has a great impact on the cost of the project, and efficient interoperability has been shown to improve errors and lead to changes in construction design and operation (Nederveen et al., 2010). The Cabinet Office believed that by using a collaborative environment in a shared platform the cost of transactions and the opportunity for errors would be reduced dramatically. However, a lack of a well-matched system, standards and protocols and the fluctuating requirements of clients and designers have inhibited the adaption of technologies, which can ensure that all disciplines are working from same data (Cabinet Office, 2011). The recent construction strategy for the UK (Construction2025, 2013) established by government listed the further benefits of interoperability as the following: increased speed of overall project delivery, reduced infrastructure vulnerability, greater reliability of information through the lifecycle, an expanded market for companies, decreased supply chain communication costs and improved value to customers (Construction2025, 2013).

The accurate information which is created in structural engineering domain shall represent following factors precisely; space, weight, stiffness, cost effectiveness and construction materials. Geyer (2009) argued that structural engineering information should be optimized in parallel with design process. The criteria for structural engineering information optimization are be categorised as quantity of **resources** which is required for building. Resources is a significant criterion which represent the cost of expenditure for structural zone to be constructed, the amount of material for structural components, The amount of energy for installing structural elements and the area that structural zone will be occupied. In contradiction of the resources, the **design preferences** is the another criterion that should be taken into consideration is structural design optimization. Bailey and M.Raich (2012) developed a preference prediction model that evaluates user preferences as an explicit design in the optimal geometry of roof trusses.

2.2.4 Impacts of Business Workflow and Organisational Culture on Structural Information Management

During attempts to utilise integrated information technology solutions and integrated digital models, most structural engineering companies need to alter their traditional business workflow and organisational culture (Palm, 2004). Development of information technology without appropriate consideration to organisational culture and business strategy cannot contribute to enhance information quality (Gjendran and Brewer, 2007). As it has also been indicated in section 2.1.2, traditional structural information modelling consists of reworks, repetitive deliverables information, review process and clash detection. Integrated-based and intelligent information modelling technologies can reduce errors and reworks and improve availability of information results from engineering modelling and documentation (Palm, 2004). In addition to the provision of sufficient budget for investment in the adoption of novel information technology, engineering organisations need to allocate sufficient time for individuals to learn the use of technologies and adapt to the business plan, and this would have a dramatic effect on the adoption of suitable information technology by the engineers thereby helping achieve maximum levels of information quality.

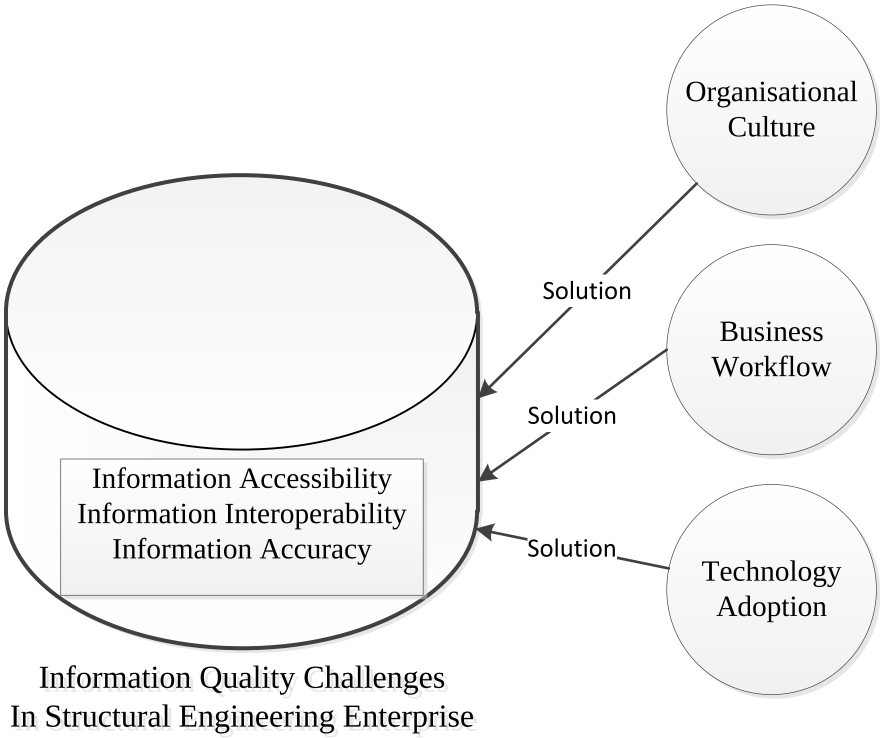


Figure 2-11 Information challenges in structural engineering enterprise (by author)

According to Figure 2-11, the three critical factors of information quality that have been identified in the literature review (information accessibility, information interoperability and information accuracy) can be supported by organisational culture, business workflow and technology as shown in Figure 2-11. Building Information Modelling (BIM) has been introduced to all AEC stakeholders as an information management philosophy which covers all organisational culture, business workflow and technology points of view. BIM can helps structural engineers stay flexible and competitive by giving them the ability to better predict the outcome of their structures before they are built. With BIM, structural design and documentation can be integrated earlier in the process, so design interferences can be addressed before construction begins. And bidirectional linking to analysis applications from leading industry and regional partners helps reduce coordination errors and improve accuracy. BIM also helps to more efficiently to accommodate design changes as they occur, and improves coordination with extended teams. This research focussed upon BIM as a method of information management to enhance the main information quality aspects in structural engineering by modifying organisational culture, business strategy and technological adoption.

2.3 Chapter Summary

This chapter reviewed the literature in the context of information management challenges from broad view of AEC industry towards structural engineering sector accordingly this is in respect of objective 1 of this research. The first objective of this research was formulated to examine key information management challenges related to structural engineering discipline. Therefore, the initial sections of this chapter were devoted to a review of related information that describes the nature of information management in structural engineering discipline. By understanding the components of information management in structural design the requirements of this sector can be well understood. From the literature it was appreciated that the challenges in information management in structural engineering are not separate from the rest of the AEC industry. However, there was insufficient evidence in the existing literature to support this view, hence, for this study data was collected directly from the structural engineering field. This chapter identified from the literature, main information management challenges in AEC industry and particularly in structural engineering sector can be categorised under information quality umbrella. The three main dimensions of information quality challenges in structural engineering sector have been specified in this chapter include; information accessibility, information accuracy and information interoperability. It can be finalised from this chapter that the solution for improving information quality dimensions may be accumulated by technology adoption, organisational culture and business process strategy in information management system.

CHAPTER 3. CONTRIBUTION OF BIM TO STRUCTURAL INFORMATION MANAGEMENT

The main purpose of this chapter is to review the literature to understand the potentials contribution of Building Information Modelling (BIM) in structural engineering discipline and to examine key BIM solutions for adoption related to management of structural engineering information. BIM value proposition for AEC industry, technological aspects of BIM, BIM-based workflows and human resource readiness for implementing BIM are explained in detailed. This chapter collected the state of the art literature in the context of BIM technology, process and human resources to address objective 2 and further addressing objective 4 of this research as mentioned in the Section 1.4.

3.1 BIM Value Proposition for AEC Industry

The idea of BIM was developed in 1970s. At the beginning the name was building product modelling (Eastman, 1975). The term BIM is used extensively for information management within design, construction and facility management industry. BIM has been determined in some articles (Succar, 2009, Succar, 2010) as a set of interacting policies, processes and technologies. Penttila (2006) determined BIM as a "*methodology to manage the essential building design and project data in digital format throughout the building's life-cycle*". Recently the demand of BIM in construction market has increased, particularly in large companies. In the UK the cabinet office has published a construction strategy which all the project and asset information is being requested to be submitted in collaborative 3D BIM by 2016 (Cabinet Office, 2011).

BIM enables multi-disciplinary working thereby enabling more rational decisions and reducing mistakes and reworks by providing the right information to the right people at the right time. However, in order to encourage stakeholders in the construction industry to investigate BIM, the advantages and boundaries of this technology should be identified. Yan and Damian (2010) illustrated the advantages of BIM, which can be seen in Figure 3-1. According to them, time, human resource and cost reductions are the most influential factors for American and British AEC companies when utilising BIM. The survey concluded that 16% of AEC companies in the UK and 33% in America companies are using BIM; thereby, this implies a low uptake.

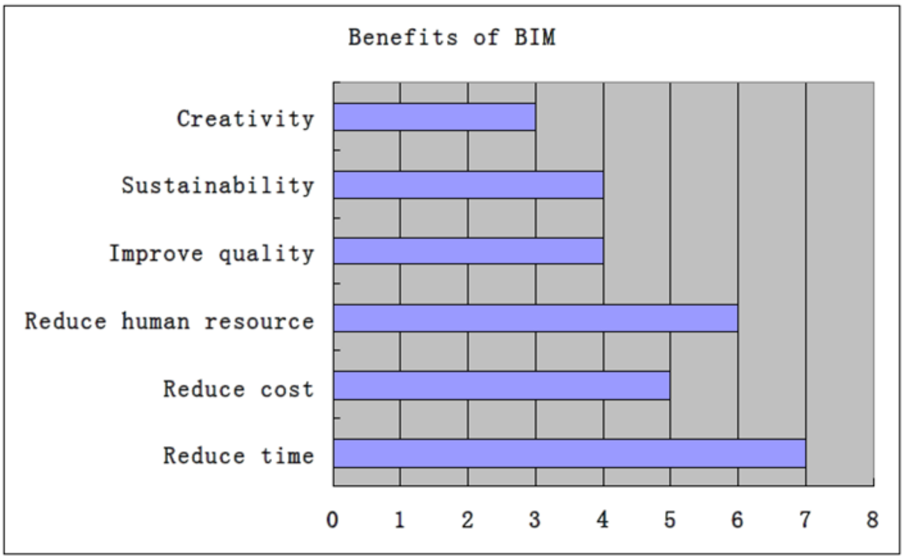


Figure 3-1 Advantages of BIM (Yan and Damian, 2010)

Adoption of BIM has been shown to improve construction design productivity with resultant cost reduction and increased service engineering to other participants such as the client and the contractors (Sacks and Barak, 2007). It is believed in state of the art literature that BIM can facilitate design and construction process by involving different disciplines through automated simulated information. It will assist to addressing conflicts, communication regarding design alternatives , cost effective and time saving (Li et al., 2014). However, before incorporating BIM, structural engineers must consider several technical issues which include misaligned connections, inaccurate features and geometry conflicts. Most design firms adopt BIM with the aim of increasing productivity and quality of their designs and drawings. Several reports suggest that the process of checking the drawings in construction industries consumes 83% of the labour time; however, there is no mechanism in place for reducing these errors from occurring from design trough to construction stage. Although there is no instant reduction in man-hours by adopting BIM, the error reduction in design drawing is a key advantage (Kaner et al., 2008).

A key advantage perceived by some contractors and design firms is that BIM provides a database of information which could harmonise engineering and management processes. Azhar et al. (2008) pointed out that BIM highlights n-dimensional models to simulate all phases of construction projects. Hence, BIM could help architects, structural engineers and manufacturers to visualise the simulated n-dimensional model of what needs to be built.

Table 3-1 shows the SWOT analysis of BIM for precast concrete engineering projects. Table 3.1 represents the strengths, weakness, opportunities, and threats of implementation of BIM in structural engineering companies. Table 3.1 reveals that implementation of BIM in structural engineering companies has the potential to enhance design productivity and reduce design errors and reworks on one hand, while on the other hand it is a very challenging proposition. Kaner et al (2008) emphasised that BIM can potentially contribute to enhance quality of precast concrete design information in terms of accuracy and reliability of the information. However, structural engineering companies for improving their quality of information have to increase their knowledge of BIM-based modelling and develop error free drawings with minimum editing requirements.

Table 3-1 SWOT analysis of BIM for precast concrete engineering (Kaner et al., 2008)

Strengths Skilled engineering staff experienced in CAD and other software Appropriate IT infrastructure, access to advanced software Leadership with vision	**Weaknesses** Skilled operators are in short supply and are costly to train Adoption requires capital investment
Opportunities Increased engineering productivity Enhanced competitiveness of engineering services through reduced design lead times and the virtual elimination of geometry and design consistency errors Provision of new services for owners and contractors (e.g. visualisation for conceptual design, rapid and accurate quantity take-off and estimating, data for monitoring and managing production and erection)	**Threats** Varying workloads Dependence on a small number of engineers skilled in BIM Staff that are unable or unwilling to adapt may feel threatened Drawings cannot be produced fully automatically: ‘manual’ editing is still needed Inability to remain profitable without BIM if competitors adopt

BIM consists of several concepts and components, but the relationships between these components and concepts are not well understood by the industry. Succar (2009) emphasised on necessity of a BIM framework which can represent divergence of domains, components of each domains, relationship between components and industry requirements to implement BIM according to specific discipline and geographical locations. BIM framework can be presents as networks of nodes and relations. The first stage of developing BIM framework in most of the literature consider on various tiers of underlying BIM aspects (Succar, 2009, Succar, 2010, Steel et al., 2012). Taylor and Berstein (2009) claimed that most of BIM researchers concentrated merely on technological aspect. However, recent advances in BIM examined different dimensions for utilisation and adoption of BIM in the AEC industry. For example, Jung and Joo (2011) highlighted three dimensions of BIM framework in construction industry; BIM technology, BIM perspective and BIM business function.

This research examined a BIM framework which describes technological variables according to adoption across business process and organisation perspective in construction domain. There are some researches that developed frameworks for BIM implementation which highlighted Three aspects for BIM; technology, people and business process (Building Smart UK 2010, Staub-French et al 2011,(Gu et al., 2014). Nepal et al. (2014) added the fourth dimension to BIM framework which is Project context. They argued that all four BIM dimensions are interlinked and it is very important to consider interrelationships of dimensions for evaluating BIM implementation and performances. In the following sections contributions each technological, workflow standards and human resource readiness aspects of BIM in structural engineering information management are discuss in detailed.

3.2 Technological aspects of BIM

One of the key areas in BIM domain is technological development. An understanding of the potential BIM technological contribution to AEC industry is needed by the structural engineering industry. In this regard, the potential benefits of incorporating IT in the structural design industry have been studied and the key tiers of BIM technologies have been compiled from the existing body of knowledge. These are; 1- Visualisation Tier, 2- File Format Standards and Document management Tier, 3- Semantic Tier, and 4-Software Tier. The following parts of the research are devoted to the examination of these tiers.

3.2.1 BIM Visualisation Tier

Since the 1980s there has been a dramatic move from computers using algebraic and numerical values to symbolic models and values. In this context, two concerns are raised; 1- Converting human understanding of an artefact into a computer representation (coding) and converting a computer representation into human interpretation (decoding) and 2- Representing this in an explicit way by considering intentions and purposes (Mathur et al., 1993). Regarding coding in the visualisation level, designers have several alternatives to input data into machines such as the colours, textures and size of the model. And regarding decoding the model, model viewers provide several options to view the model such as zooming in. With reference to the visual exchange model, the opportunities for leveraging models depend progressively on the semantic level (Steel et al., 2012). In terms of the collaboration design, semantic interoperability concerns will arise (Yang and Zhang, 2006) such as:

1. Sharing of building information modelling occur by using different project participants, different definitions of terminologies, different meanings of information and different perspectives of design.
2. Disparate design systems and heterogeneous data sources with proprietary information.
3. Fundamentally different representation languages and data formats, which are used in data, interchange processes.

The most common method of building design representations are categorised in; 1- Arbitrary codes (highly abstract means of communication based on common notational language to signify ideas), 2- Graphics (sketches, renderings, perspective drawings and photographs), 3- Scale models (which provide information concerning volumetric properties) 4- Mock-ups (which allow the spectator to recognise how the realised design will appear) and 5- Prototypes (the mock-ups which are made from the actual material to be utilised)(Kalay, 2004). The geometric entities such as points, lines, planes, rectangles etc. are traditionally represented as 2D CAD and generic 3D modelling programs. In the AEC design industry general geometric representations are developed to create object-based data models. Such data can be rich in information regarding building lifecycles and can be utilised in visualisation, documentation and analysis (Khemlani, 2004).

Virtual models can be surface or solid models. Surface models are applied for visualisation purposes and the information used by this type of model is size, location, shape etc. The solid models are often referred to as smart models (SMs) and these kinds of models are often created by solid generator modellers. Their domain is more than the visual aspects of building components and, in addition to physical information; those contain information about the nature of objects; for instance, the locations of objects and their relation to the locations of other objects, the quantity of objects and so on. Solid models with parametric components are also called object-based model (Kymmel, 2008). The architectural, structural and Heating Ventilation and Air Conditioning (HVAC) models generated by design companies can be combined into a composite model for total visualisation. The interoperable challenge merges during collaboration by applying various software tools.

Innovative methods of representation of these models have been incorporated in some existing BIM tools. For example, Naviswork allow users to select an avatar to walk through the model. In such a way a third-person-view could help the user to achieve a more efficient sense of scale; nevertheless, Naviswork's capability for avatar navigation is not incorporated (Shen et al., 2013). Virtual reality tools have generated the built environment's outputs with the purpose of facilitating the interaction between the designers and clients. For instance Figure 3-2 indicated 3D steel frame model which was created by Tekla software. In this software, all functions such as modelling, loading, analysis and design that are needed from the initial conceptual design phase to the final detailed design phase are covered by a single model. in that case clients can go along the movement of avatars to monitor their daily activities while in the building they can additionally switch between different end-users, as multiple observation angles are provided, functions such as 'zoom', 'move' and 'rotate' are obtainable for the observation and the 'free observation' mode is available for users to control an avatar to freely walk through the building (Shen et al., 2013).

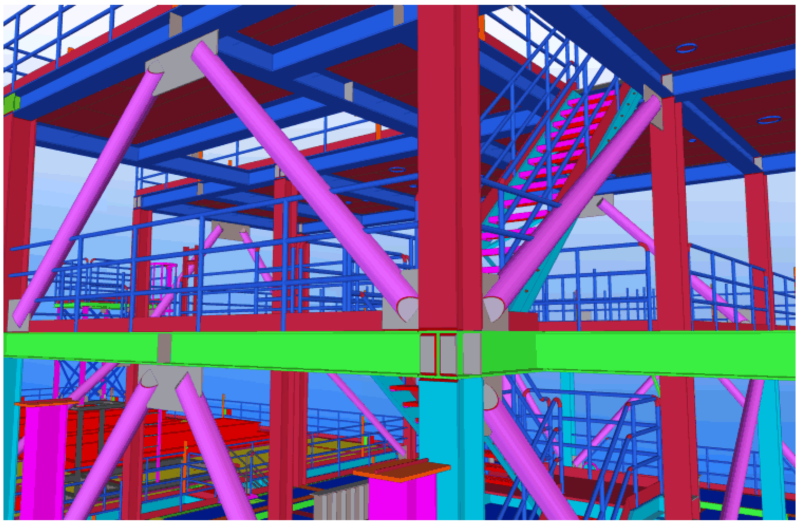


Figure 3-2 Structural Zones 3D Visualisation (Tekla, 2014)

In building design stage, integrated design system is suggested for enabling architectural and engineering system to work effectively together (Intergovernmental Panel on Climate Change, 2007). The use of *building performance simulation* (BPS) tools are significant contribution of BIM to an integrated building design approach particularly to support design decisions in building energy efficiency (Hetherington et al., 2011). Architects and engineering requirements in the choice of BPS tools are studied and ranked by Attia et al. (2012) among architects and engineers through surveys. That article classified building simulation performance into five criteria; 1- usability and information management of interface, 2- integration of intelligent design knowledge-based, 3- accuracy of tools and ability to simulate detailed components, 4- interoperability of building modelling and 5- Integration of tools in building design process. As it can be seen in Figure 3-3, there is a broad gap between architects and engineers' priorities in the choice of simulation criteria. The accuracy and ability to simulate detailed and complex components is the most important criteria for engineers in the context of simulation tools.

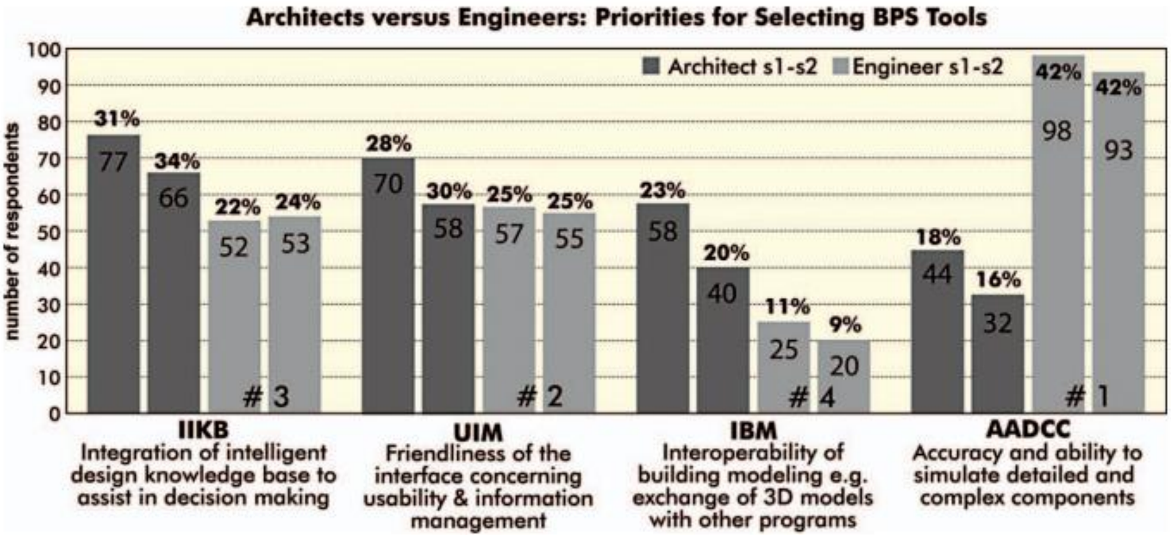


Figure 3-3 Ranking the most important features of a simulation tool (Attia et al., 2012)

The other key criteria in building simulation is categorised under the umbrella of design support and design optimisation. The optimisation in building science is referred to processes of creating a design or decision as fully perfect, functional and effective as possible. Several researchers utilised optimisation term to indicate computer simulation abilities to reach sub-optimal design solutions (Wang et al., 2007, Goia et al., 2013). An effective simulation-based optimisation will contribute into several building performances' requirements including; sustainability, low-energy building, low carbon building, passive houses, etc. Nguyen et al. (2014) categorised building optimisation process into three stages which are, pre-processing stage, optimisation stage and post processing stage. In the pre-processing stage it is worth to take consideration into building model be *simplified* however, it should not reach over-simplification due to inaccurate modelling of building (Magnier and Haghighat, 2010). The most important criteria in optimisation stage is monitoring whether final solution is achieved by the algorithm. And in post processing stage solution outputs will be interpreted by experts (Nguyen et al., 2014).

The several visualisation and simulation tools which are available for structural engineering information modelling are recently discussed. And the key variables that literature considered in visualisation and simulation of information are discussed in this section. The following section studied the second BIM technological tier and its contribution to structural engineering information management

3.2.2 BIM File Open Standards Tier

Special considerations arise in the exchange of data between different BIM tools. Mere reliance on visual aspects alone is not sufficient, and there are other challenges faced by designers during data exchange. In broad terms three main factors determine the degree of success in the exchange of 3D models between any two applications: firstly, performance of the export and import translator functions embedded in the BIM tools. Secondly, internal structure of the neutral file format supported by BIM tools and thirdly, the range of data object types to be communicated (Jeong et al., 2009).The designers in different multi-disciplinary parties create their models via different tools. Firstly, modification between different tools has to be translated. Secondly, any change has to be communicated to each design discipline, who should then adjust their portion of the model by reviewing the impact on their performance domain (Citherlet et al., 2001). Therefore, the requirement for building specific data emerged in the context of CAD attention. Specific translators have been developed to meet the requirement of direct communication between diverse applications that have been created by different commercial vendors.

Industry Foundation Classes (IFC) is an important information model to ensure interoperability. In this context the IFC was invented in 1999 by the International Alliance for Interoperability (IAI) to support interoperability through various disciplines with specific applications which are applied in design, construction and maintenance of buildings by capturing information throughout the lifecycle in all aspects of building (Khemlani, 2004).

Interoperability of IFC depends upon the ability to utilise different languages for representation of its data. It has to be appreciated that the IFC platform is not restricted to a single software vendor, and is independent of a special vendor's plan for developing software (BuildingSmart, 2013). The IFC attempted to create a parallel collaborative platform, which was Standard for the exchange of product model data (STEP) and was initiated in 1984 by the International Standards Organization (ISO). There are several languages that can be used to present IFC model data. "EXPRESS' language is one approach for exchanging the full IFC model. Express files comprehend models in a very compact format and permit them to be re-indexed while the information is loaded onto a server or other IFC-compliant software tool (Nisbet and Liebich, 2007).The Extensible Mark-up Language (XML) is another representation of IFC data, has a more comprehensive range of supporting utilities and database implementations and is the basis for most e-commerce messages and web services

(Nisbet and Liebich, 2007). Over the last decade, XML has been applied to the exchange of information via the Internet. A typical XML document is combined of two files; first the tangible XML file, which contains data, and second the file itself, which describes the structure of the data file (Yen et al., 2002). In the past Document Type Definition (DTD) files were utilised to determine the structure of XML; however, in 2001 W3C developed XML schema (XSD) to determine XML structure (W3C, 2001). The most significant contribution XML offered for the construction design and management was to allow a structured data exchange between various parties (Agdas and Ellis, 2010) and the IAI developed the IFCs to ifcxml (Bakis et al., 2007). The aecXML was established under the administration of IAI due to the contribution of XML to different aspects of the construction industry. The structure of building systems in the IFC model are defined by placement and physical representation, which can be seen in the table below (Eastman, 2007).

Table 3-2 Structural IFC entity from (Eastman, 2007)

Structural Entity Name
IfcBeam
IfcColumn
IfcCurtainWall
IfcRamp
IfcSlab
IfcStair
IfcWall
IfcRailing

Data representation by IFC is not merely restricted to cover tangible components such as beams, slabs, walls, etc. but also entities such as activities, schedules, costs, etc. All of the entities in the IFC model can have various attributes like geometry, materials, and relationships and so on (Khemlani, 2004). However, the IFC is not the only interoperability standard used in the construction industry. Conventionally, IFC files have been applied to exchange architectural models by using traditions such as walls, floors, doors, windows, stairs, etc.

The application of IFC files in the case of structural exchanging information is a more recent development however, IFC-based model exchanges are incomplete and error prone

(Kiviniemi, 2008, Eastman et al., 2010). The main reason for error and incompleteness of IFC-based exchanges is related to inefficient defining of ontology structure available in IFC schema (Venugopal et al., 2012). When meanings of the terms and relationship between terms are well defined in different domains of structural elements, (For example steel domain, concrete domain, precast domain etc.) it permits structural design and model viewer applications to present and interpret models in unambiguous approach.

There are several researches that have been conducted to define different ontological scopes of structural model schema. Vanugopal et al. (2012) developed ontology definitions for precast structural model, and it consists of several classes; components, connections, systems, placement, material, geometry and requirements ontology. Three key ontological syntaxes are defined for each structural precast object; object representation, material association and placement of object.

The CIMSteel integration standards (CIS/2 file) were developed to enable steel structure information representation modelling. The definition of structural steel in CIS/2 is detailed and comprehensive although in IFC it is more generic and not as broad (Lipman, 2009). In the context of structural engineering information, the CIS/2 integration format is the electronic data exchange product model for structural steel information (Crowley and Watson, 2000, Shan et al., 2012). CIS/2 permits data exchange between different programs on the condition that those programs have a translator for interpreting the neutral data of CIS/2 into the programs' native format.

Structural steel is modelled in different views by CIS/2 and IFC, and to ensure interoperability, Eastman et al. (2005) developed mapping from the CIS/2 product to the IFC product model. That mapping allows steel models to be imported into the IFC package to perform model coordination between other parts of the construction model; for instance, walls, floors, doors, windows and mechanical systems to structural steel systems. Normally, CAD software is used to import and export IFC files and not CIS/2 files and is the most software specific to steel design, analysis and detailing only supports CIS/2 files (Lipman, 2009). Due to this fact, the intention in developing mapping between CIS/2 and IFC2X3 was only taken into consideration. In addition, IFC test files which are generated for applying entities to model structural steel have not been commonly implemented (Lipman, 2009, Lipman et al., 2011).

Although there lots of efforts have been done to convert structural engineering information into digital structured format, this claimed there is still large volume of unstructured information either delivered to structural engineering company or produce within structural engineering organisations via dialogue or text. In spite of the great progression in recent construction design technologies, unstructured data is an important issue that needs to be addressed to enhance quality of information. According to Caldas et al. (2005), structured data is defined as data that has a database and is usually in a software system that uses a form of database in the background. To clarify, Zhu et al. (2007) pointed out that in the unstructured data there is a serious lack of descriptive data in the documents. For instance, a Microsoft Word document is an unstructured document but Microsoft Word allows a user to define descriptive data about the document such as the name of the author and the date. With reference to the pilot study that has been conducted here the highest amount of construction project information is text-based documents; for instance, contracts, field reports, order changes and information requests (Caldas et al., 2005).

The heterogeneity of information in the AEC/FM industry relates to the coexistence of structured and unstructured data (Kosovac et al., 2000). Structured information indicates whether it is machine understandable, such as IFC and aecXML, but unstructured data is human understandable, such as video, audio, images, word processor and Hyper Text Mark-up Language (HTML) documents. Kosovac et al. (2000) highlighted that to fully deliver the interoperability requirements of the AEC/FM industry; the incorporation of structured and unstructured document based data should be facilitated.

The amount of unstructured information increases from conceptual structural design towards detailed design. The big challenge is managing big unstructured data according to three main issues; volume amount of data, variety data types and velocity speed of input and output (Pettey and Goasduff, 2012). In the context of structural engineering domain, large volume of unstructured information produced from incompatible software program Jiao et al. (2013) and from dialogue conversation between design coordinators (Addor and Santos, 2014). Incompatible software which is used in structural engineering domain is including; Autodesk’s DWG, Bentley’s DGN, Microsoft Office formats’ DOC/XLS/PPT and image format’s JPEG. Addor and Santos (2014) indicated that visualise floor plan and writing down text are the most frequent methods of information exchanges and information capturing in meeting rooms during building design phase. Structured data is an important consideration to ensure interoperability.

Structural engineering sector as a main part of building engineering information producer presents geometric information, parametric information and reports information to meet legal regulations. It has already been mentioned that the available solution to support the integrated information management in construction design and management could be one comprehensive standard information model like IFC and CIS2. These standards could be applied to reference documents. However, in the current AEC/FM projects there are two kinds of data models: model-based systems and text documents. As such, the mechanism for mapping between documents and model objects would then have a significant role in achieving this integration (Caldas et al., 2005). Some studies have argued that although there are many types of information in building components and construction processes like IFC, it is possible to apply metadata models to the unstructured context and connect unstructured substances to model-based information systems (Mao et al., 2007, Zhu et al., 2007, Jiao et al., 2013, Li et al., 2014).

The several comprehensive file standard tools which are available for structural engineering information modelling and the key contributions that literature considered in interoperability and accessibility of information are discussed in this section. The following section studies the third BIM technological tier and its contribution to structural engineering information management.

3.2.3 BIM Semantic Tier

Accurate sharing of information between multiple disciplines is an essential for modern construction design projects. This is to ensure that each party can manipulate a large amount of documents via various computer-aided management systems. The concept of facilitating information sharing would not occur in the AEC industry except in terms of human understanding. One of the methods that can be pursued to address this problem lies in making the information understandable to both humans and machines and information should be labelled in a way which makes their meaning explicit (Pan, 2006). The concept of semantic information will be represented in this study in relation to web service and anthology engineering context.

In the course of semantic web service, the major goal of a semantic idea is to provide structure to the content of web information so it can be accessible, able to process and interpretable by computers in parallel with human beings (Berners-Lee et al., 2001). The semantic web is an extension of the present World Wide Web. The structure of the current web contains Uniform Resource Identifier (URIs), Extensible Mark-up Language (XML) and RDF (Resource Description Framework) and by developing RDF schema and ontologies the semantic web can be presented (Berners-Lee, 2003). In the following Figure 3-4 the structure and components of the semantic web are outlined.

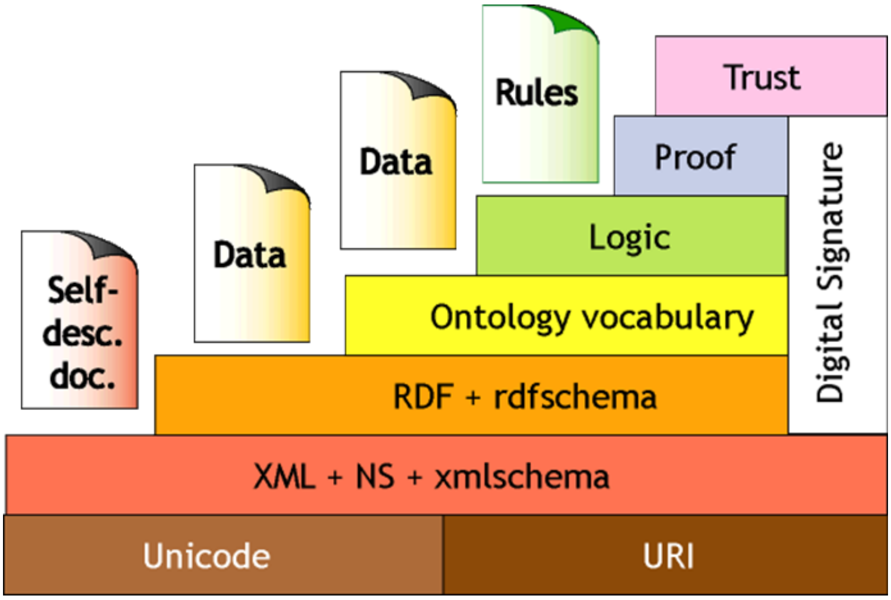


Figure 3-4 Semantic web tower (Berners-Lee et al., 2001)

Mark-up languages are used to present information on the web. The above figure illustrates that the fundamental components of a semantic web are URI and Unicode. In order to be accessible by applications, each data model or data object must have a unique and universal identification. These identifiers are referred to as URIs. Extensible mark-up language (XML), Web Ontology language (WOL), Resource description framework (RDF) and Semantic web rule (SWR) allows URIs point to things (Fensel, 2001). The standard mechanism to structure, share and interpret the data between applications will be provided by XML (Ding et al., 2002). XML is a type of mark-up language and mark-up language is used to present information on the web. Both HTML and XML are categorised by the fundamental standard of all mark-up languages, which is Standard Generalized Mark-up Language (SGML). RDF is a framework to assert resources in the model that consists of objects, properties and values.

Every element in this framework could be linked by semantic links that permit queries on one database to be converted into queries on another. RDF schema affords a framework to determine the properties and the classification of those properties in hierarchies.

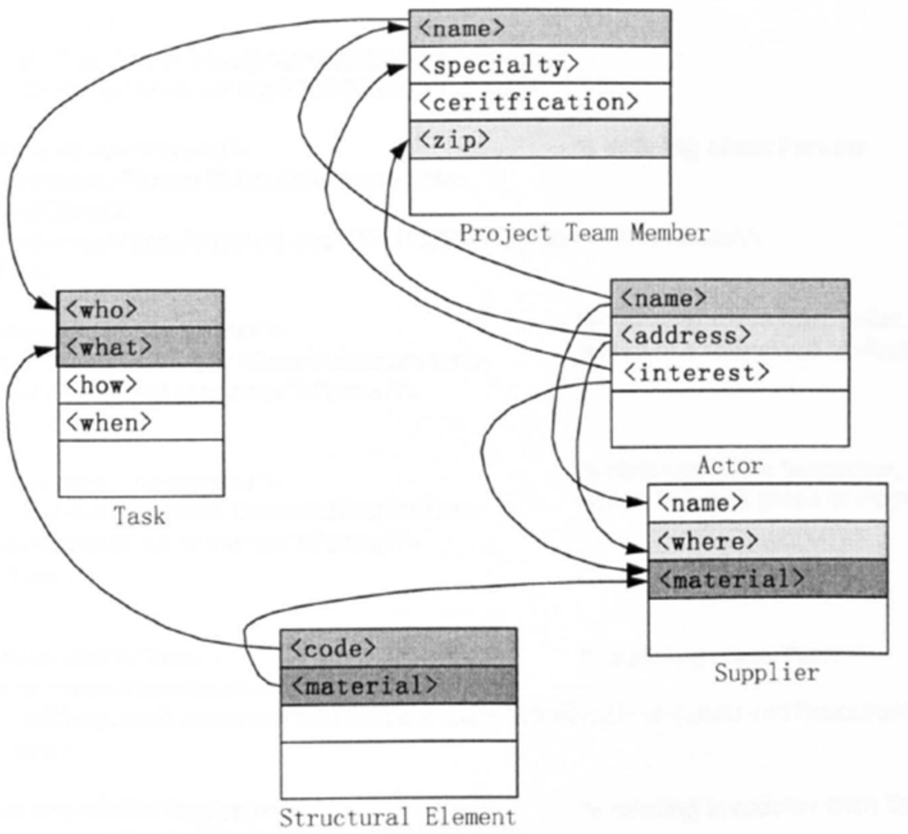


Figure 3-5 Example of semantic links of RDF data (Pan, 2006)

Ontology enables the sharing of understanding of a domain that can be communicated between applications and people. As illustrated in Figure 3-4, ontology forms the heart of a semantic tower. Web Ontology Language (WOL) has been implemented as a language to determine the classes of information and the relations between those classes (W3C, 2004, Bodenreinder et al., 2003). Ontology develops an agenda for representing, sharing and managing information within a system. Bodenreinder et al. (2003) argued that there are two types of ontologies; 1- Domain ontologies, which is a representation of vocabulary and classically is designed represented to a particular subject matter. For example, in structural engineering design an ontology for the domain of structural engineering can have elements such as “simulation”, Finite Element Method (FEM), “Steel Cladding System” and relations between elements, such as “a designer simulate steel cladding system using FEM” and 2- Upper level ontology, which portrays generic information that holds across many fields.

The terminology used in data representation is an important consideration. In building design, the data contents can be categorised into two types: 1- Geometry and 2- Object-based property (Jeong et al., 2009). In multi-disciplinary building design, any variety of data representation should provide meaningful information for other participants, constructors and clients. In this case different terms may be utilised to represent similar perceptions or a single term for different perceptions (Yang and Zhang, 2006). In other words, the designers frequently share the same objectives; for instance, in proposing a design solution which meets a client's requirements, they would not essentially use the same terminology to communicate in the design practice.

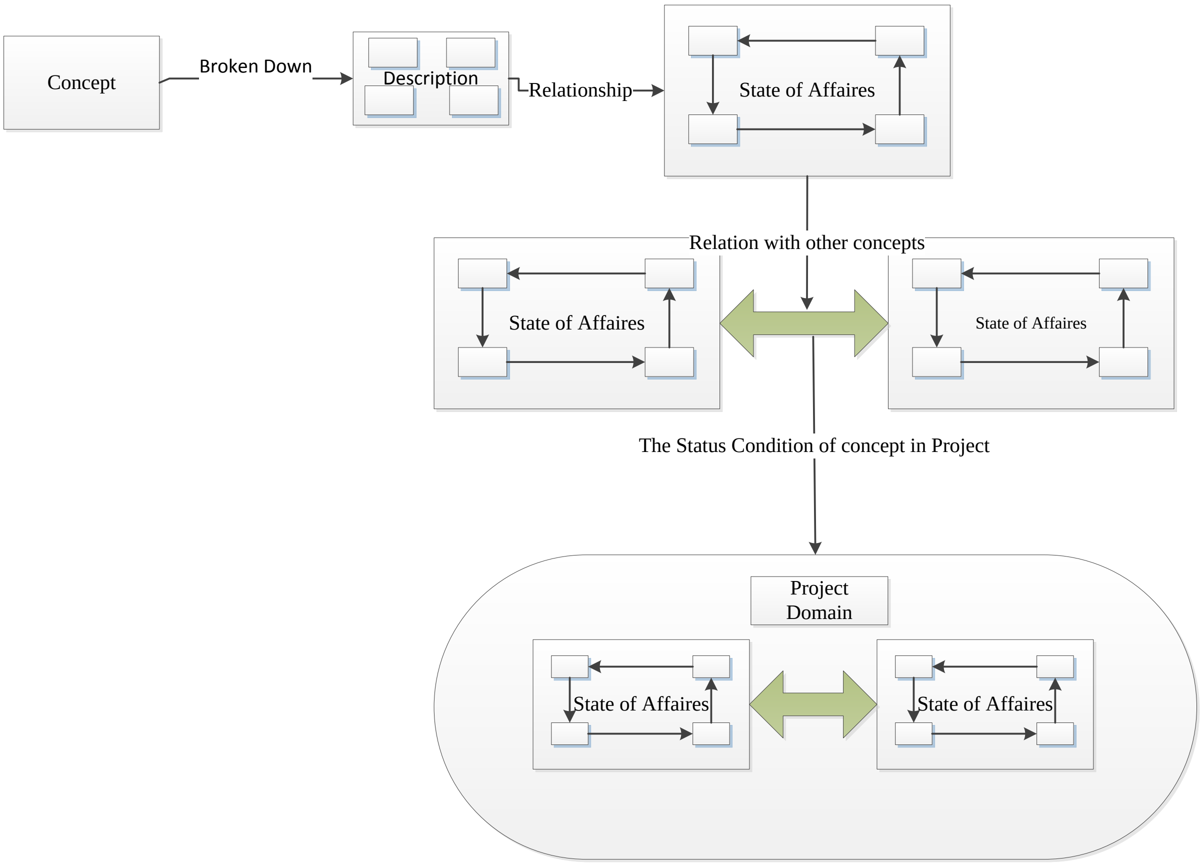


Figure 3-6 Conceptualisation of concept from author

The formalisation processes for building ontology of a concept in the AEC and structural engineering domains is described in Figure 3-6. Each physical structural element or abstraction could be defined as a concept. The user or actor breakdown the structural element into sub-concepts and each sub-concept need to be defined in description phase. For instance the foundation of a building can be specified as a concept. And this element can be divided into several bars, piles, concrete, base plates, bolts and etc. In this phase the attributes of each concepts will dependently described such as; weight, cost, manufacturer etc. In the next step, the situational conditions of each sub-concepts and relationship with other sub-concepts will be specified in state of affair step as shown in Figure 3-6. The situation of each concept is specified by location, position, setting, completed installed or delayed. And the relation with other sub-concepts describe by “set-by” and “part-of” descriptions. The relation between main concepts and the status, position and location of each main concept will be specified in whole project domain. There are many tools available for providing functions to retrieve, update and validate ontologies (Park et al, 2013).

To ensure better communication between different professionals and systems, several efforts have been conducted to develop a well-organised construction concept vocabulary such as Talo90 (Talo90, 1999), Uniclass (Uniclass, 1997), BS6100 (BSI, 2002) and the North American Industry Classification System (NAICS, 2003). El-Diraby et al. (2005) presented a taxonomy for construction concepts to support the semantic exchange of knowledge in an e-construction environment. They believed that taxonomy is different from classification as it is a more object-oriented classification system. They used a search engine to examine the most frequent concepts and terms which are applied in construction documents. In addition, concepts from BS6100, Uniclass and IFC have been added to this concept domain and they tested the validity of the taxonomy with construction experts in Canada and the United States. The key concepts of taxonomy that El-Diraby et al. (2005) applied were categorised into seven classes; 1- The processes which are contained in sub-processes, tasks and activities, 2- The main attributes of each process, 3- The performers who perform each process, 4- The time and location of each process, 5- The requirements of each process, 6- The result or final product of each process and 7- The limitation and effects of the performances in each process.

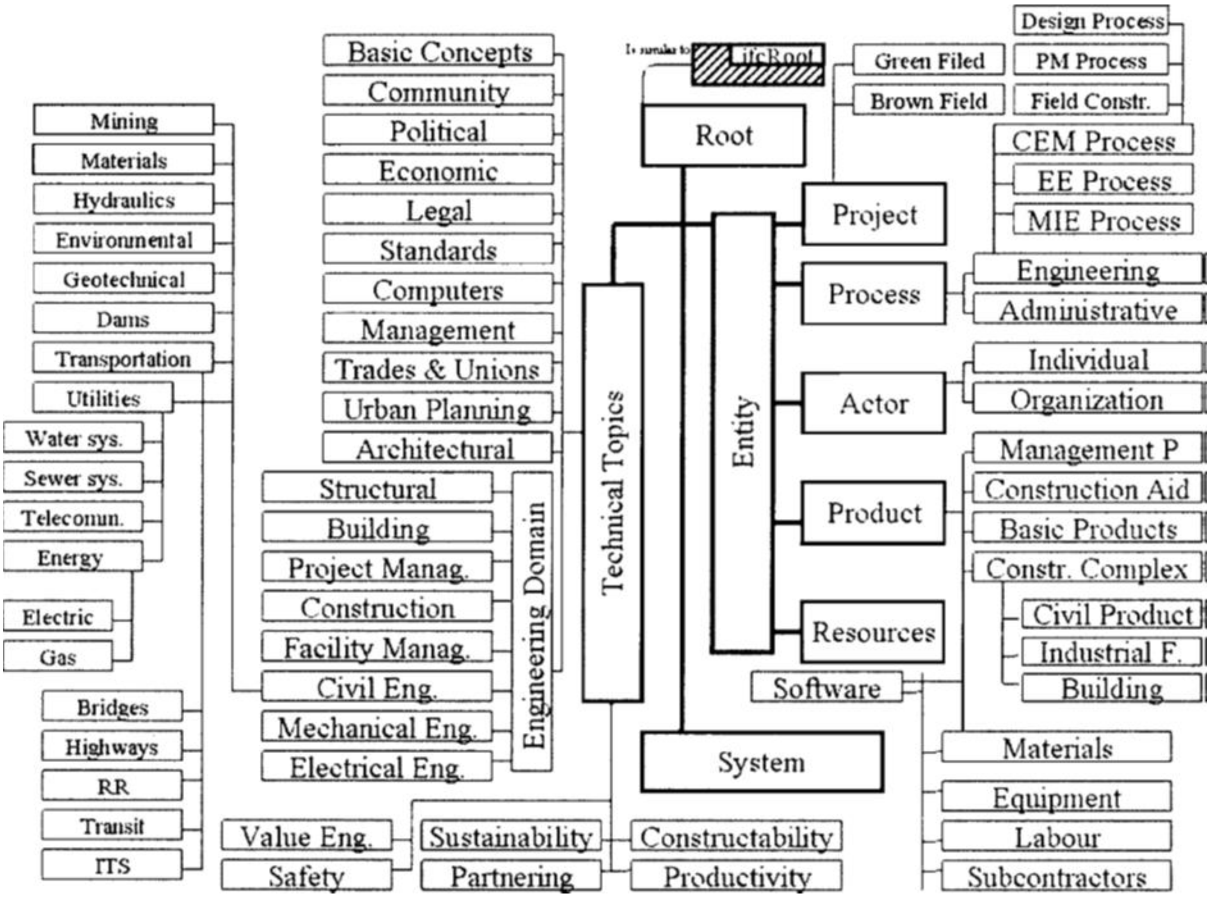


Figure 3-7 Higher level concepts of taxonomy (El-Diraby et al., 2005)

A multidisciplinary design environment entails different aims, viewpoints and backgrounds, and various terms may be used to represent similar concepts or a single expression may be used to denote different concepts. Thus special considerations have to be taken in the context of providing taxonomy in the ontology concepts of structural design. A *vocabulary library* has thus been developed to suggest commonly agreed and sharable concepts or terms in construction design and their meanings (Yang and Zhang, 2006). The interconnection between entities and the relation between attributes were classified with "is-a" and "part-of" terminologies. For instance, in CAD a structural analysis and design submitted to the server for sharing with other participants requires semantics to describe embedded information with the CAD model, which is then delivered to the server.

Semantic web is suggested for AEC industry information management at different phases particularly in design phase (Anumba et al., 2008, Pauwels et al., 2011). Several researches have been done to present how semantic web can be employed in the AEC industry target, however there is insufficient study in structural engineering information management and semantic web adoption area. Pauwels et al. (2011) developed a method to present architectural model in semantic web. Mahdavi et al. (2012) develop a semantic web technology as a solution to improve information acquisition among design analysis phase. Corry et al. (2014b) present how information beyond building context can be used to support building existing sources. For example how a semantic website like Twitter can be employ to identify building residential issues with building performances. Structural engineering sector can utilise semantic web in capturing and delivering information. Structural engineers may need to access to client's brief requirements and architects' briefing notes and sketches. The client and architect may utilise various terminologies to describe an item. In the semantic web each structural elements can be described by their context while those are input into the system and that is readable for the machine. This provides this opportunity for structural engineers to access most relative terms or meaning through their search engines. The structural engineering output information covered geometry, placements of elements, material characteristics, installation guidance, reports for presenting design decisions to meet legal regulations, sustainability reports etc. Contractors, local authorities and clients require the combination of all these information.

The several contributions of taxonomy in the ontology concepts of structural engineering have been explained. In addition the components of semantic web and contributions of semantic web in structural domain information accessibility and interoperability have been reviewed in detailed in this section. The following section studies the fourth BIM technological tier and its contribution to structural engineering information management.

3.2.4 BIM Software Tier

There is a long history of using digital information and software adoption in structural engineering industry. Structural engineering discipline requires large numerical analysis which is unmanageable without using software. The traditional engineering software tools were very isolated in respect of information interoperability and information mapping upstream and downstream (Wyatt, 2012). In the recent years software vendors developed their structural software applications based on integrated design and BIM concepts. The challenge for structural engineering decision makers is to select efficient structural software in consideration to BIM criteria. Wyatt (2012) stated in the choice of structural engineering package, the range of material properties, analysis types and design codes which are compatible with the Internet to update database is one of the significant criteria.

Most of the available structural engineering software tools are developed based on widespread information processing of the model geometry, material properties and loads. The initial geometry can be input to the software directly from architectural model, material properties can be allocated from software libraries and loading can be assigned to the model for analysis. Structural members which are generated by architectural software are not often appropriate for performing structural analysis (Eastman et al., 2008). Due to this fact some BIM software such as Revit® Structures and Bentley structures are developed to address this issues. These software tools generate structural objects which are firstly, represent information fully to achieve building code approval. And secondly, those objects are fully interoperable with their architectural siblings (Eastman et al., 2008).

Table 3-3 Structural analysis and design applications and their exchange capabilities

Structural Analysis Software	Import Formats					Export Formats					Direct Links
	CIS/2	IFC	DXF	SDNF	SAT	CIS/2	IFC	DXF	SDNF	SAT	
SAP200, ETABS	✓	✓				✓	✓				Revit Str
STAAD-Pro	✓					✓					Tekla Bentley
RISA			✓					✓	✓		Revit Str
GT-STRUDL	✓			✓		✓					
RAM						✓		✓	✓		Revit Str
ROBOBAT	✓	✓									Revit Str

There is a vital demand for concurrency information collaboration between structural software application and other design and construction domains. Due to this fact several structural software tools have been designed to support information exchange between structural applications and architectural and construction application domains. Table 3-3 illustrated some structural analysis and design applications and their exchange capabilities. Many of those software applications support detailed structural engineering including detailed structural analysis, simulations and optimisation however, there is insufficient supports for conceptual design among available applications (Wang et al., 2002, Caviers et al., 2011). Information management during conceptual design is very ambiguous process while there are not adequate software applications. Computer aided design tools are not facilitated well in order to support selecting the best solutions within various design alternatives in conceptual design phase (Rahimian and Ibrahim, 2011). The ideal digital support for structural engineering decision making in conceptual phase is to inform engineers about functions that might be arise from their solutions (Bavafa et al., 2012). This solution will reduce structural design errors and promise construction safety (Zhou et al., 2012).

The software applications in structural engineering are not merely limited in structural analysis and design applications. Structural designers would use drafting tools such as ArchiCAD and AutoCAD, model viewer such as Solibri to combine various model disciplines and optimising open standards files, project schedule tools such as MS project and safety risk forecasting tools such as CHASTE to analyse reliability of construction safety in design stage.

Sufficient literature related to the various technological tiers of BIM were collected in the present section, and these technological options and the contribution of these tools in the structural engineering field were explained. As discussed in section 1.4, the second objective of this study is to critically analyse the role of BIM to enhance structural engineering information management. Therefore this section identified the key BIM technological domains and recent tools that are available for structural engineering information management. The findings of this section contributed to this research by developing the first tier of the conceptual framework. The components of this conceptual framework in the first tier are described in this section and comprise of the technological options in structural engineering, targets of each specific option and the purpose of employment of those tools. Although various technological contribution of BIM in structural information management have been discussed in previous sections, it should be appreciated that the industry requires workflows and guidelines to illustrate the efficient way in adopting BIM for information management procedures. In the next section the BIM protocols which have been published for adopting BIM in Structural engineering industry is discussed.

3.3 BIM-based Workflows

The various technological tools available for the implementation of BIM in the structural design industry has been discussed in the previous sections, however, it has been pointed out that technological innovations cannot merely guarantee their implementation and transfer in organisations (Latour, 1987). Several attempts have been made to explain the drivers of BIM and what it entails. Succar (2010) pointed out that a set of technologies, group of processes and policies are the main boundaries of BIM. Moreover Eastman et al. (2011) also emphasized on modelling technologies and a set of processes in BIM context. BIM implementation could be complex process in the lack of efficient workflows for AEC industry and structural engineering industry as a part of this industry requires proper BIM-based workflows to implement BIM-based intelligent information management among their organisations.

The concept of BIM maturity has been stressed by Succar (2009), as a gradation of the implementation steps from the initial stages to the advanced target levels. This model of BIM maturity represents the level of maturity with respect to the capability of the AEC industry to produce and exchange information. Figure 3-8 shows the development of BIM from level 0, which is traditional CAD geometry drawings, towards entirely integrated construction lifecycle management. Level 1 is the managed CAD in 2D or 3D format and there is potential to apply some work in progress standards such as BS1192:2007 to facilitate collaboration between different disciplines. Level 2 is the managed 3D environment, in which collaboration relies more on library file management rather than file based collaboration (BIS, 2011).

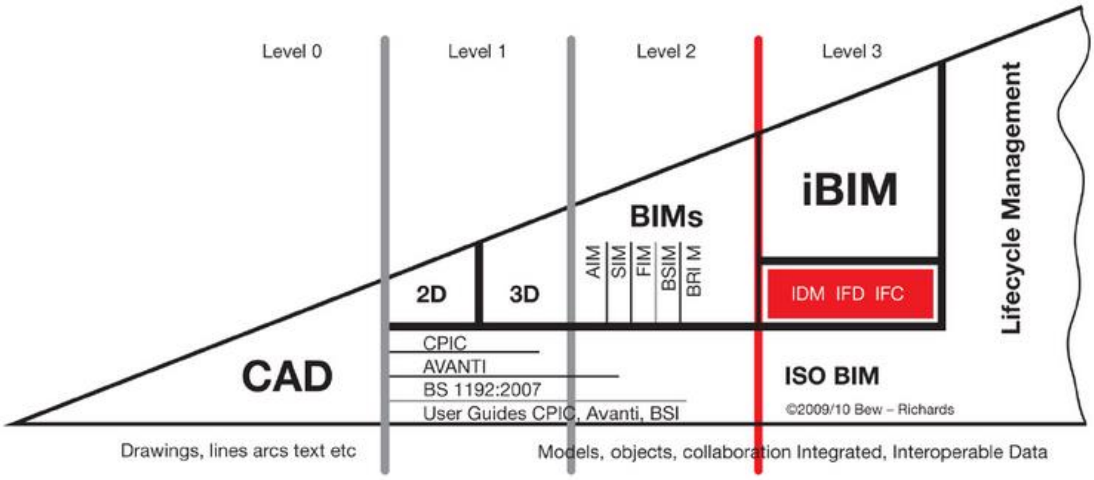


Figure 3-8 BIM Maturity Levels (BIS, 2011)

In the level 3 of BIM maturity, several standards have been published in order to provide methods for development organisation and the management of production information (BuildingSmart, 2013). BuildingSmart published data model standards that suggest the development of interoperability through information management using standard protocols. The three sides of the BuildingSmart standards; 1- Data (IFC), 2- Process (IDM) and 3-Terms (IFD) are displayed in Figure 3-9. In brief level 3 of BIM maturity is mostly an open process, which can be managed in web-based integration and by applying IFC/IFD standards.

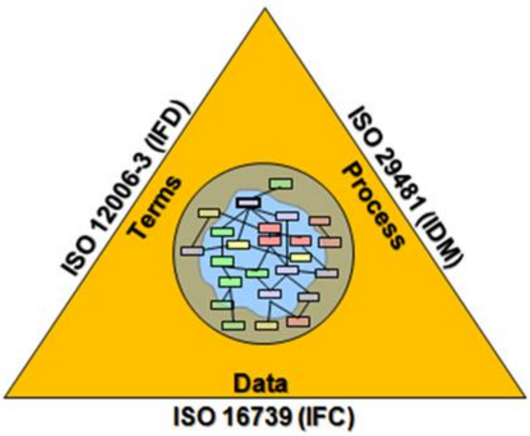


Figure 3-9 Building Smart's Standard Protocols (BuildingSmart, 2013)

To achieve successful levels of BIM implementation, a number of steps, actions and workflows have been described in the existing literature. Lack of efficiency in workflow causes failure and obstruction to successful BIM implantation. Thus, an efficient model structure would not be developed leading to a lack of collaboration and information sharing between parties. The following sections are devoted to a study of the most typical BIM workflows, both in the UK and worldwide.

3.3.1 BS1192 Standard

As a collaborative production of architectural, engineering and construction information, the BSI published the British Standard BS1192:2007. The workflow for managing the quality of construction information, applying collaborative processes in CAD, for generating and exchanging information and a specified naming policy (BSI, 2007) have all been established by this standard. BS1192 is applicable to all stakeholders, who are involved in the process of information management, throughout the entire construction lifecycle. Based on the BS1192:2007, the following consideration has been highlighted for the AEC industry in the context of BIM implementation:

- Roles and responsibilities of each design participant must be agreed
- Naming conventions must be adopted.
- Planning must be in place to develop the project codes
- A ‘common data environment (CDE)’ must be adopted
- An efficient information hierarchy must be agreed to support the CDE and document repository

Early sharing of information coupled with a confidence on the shared information has been emphasised by the BS1192 standard (Richards, 2010). In the BS1192:2007 workflow, at the beginning of each model file is created in Work-In-Progress (WIP) environment, each model file is created in the Work-In-Progress (WIP) environment at the very beginning. In this system, each participant involved in the transaction processing carry out their own work by applying organisation’s software system and each model merely contains information for which each design parties are responsible. Before uploading a model to the shared area, the model should be reviewed due to ‘suitability’ of the information provided. Especially in the case of construction, subcontractor’s documents and tenders, formal review, approval and authorisation should be done. Figure 3-10 depicts that after authorisation of the structural document, it is issued to the shared area and duplicate layers are removed. From the shared area, the models and documents would be moved to the published documentation area at an agreed milestone of the project, where the client authorises the documents and models. In the event that the client is not satisfied with the plans, the models and documents would be returned to the designers for reworking.

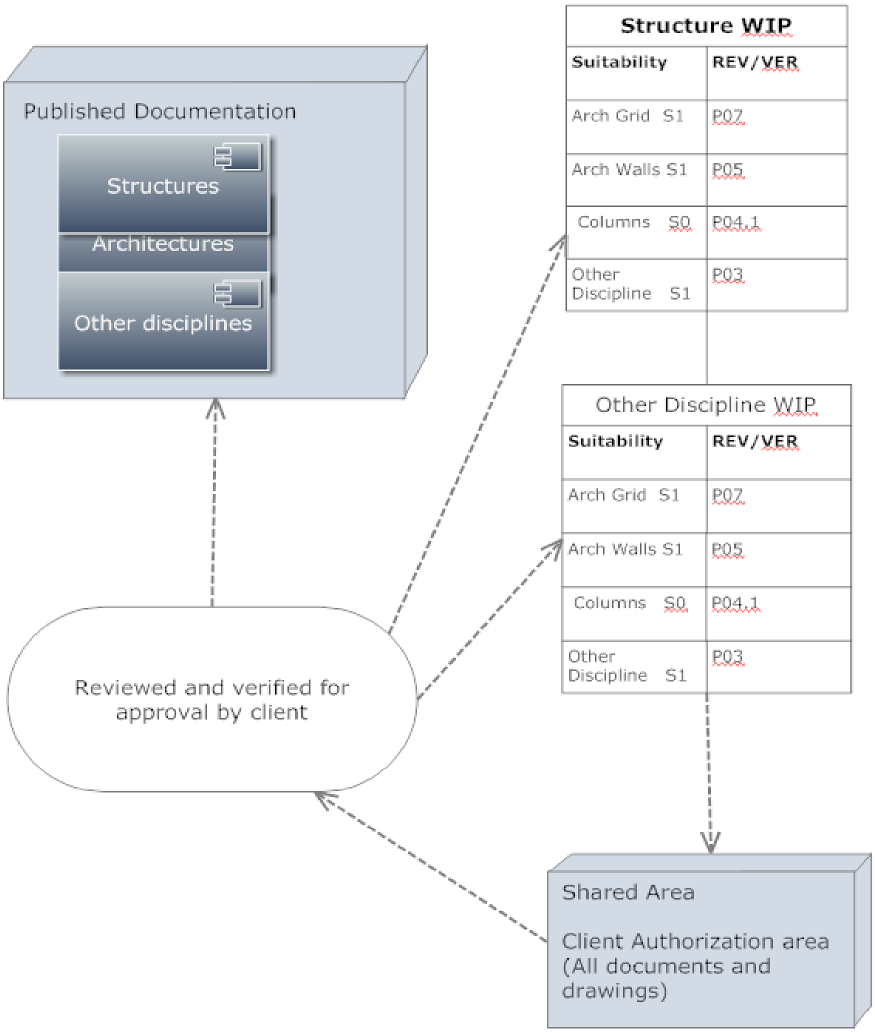


Figure 3-10 BS1192 Framework for construction information management

Quality policy, to certify that the models and documents are maintained for a lifetime, is emphasised by the BS1192:2007 standard. This standard stipulates that each model/document has to be maintained for a long time to ensure that the integrity of the model/document is preserved. Furthermore, an in-house strategy should be published and frequently reviewed. Strategic scrutiny at the time of input and persistent evaluation and checking whenever changes are made, removal of redundant information and avoidance of formats that do not maintain dimensional integrity are essential to ensure sustained information (BSI, 2007).

3.3.2 PAS1192-2

In order to provide a specific guideline related to projects that are delivered using BIM, the PAS1192-2 has been published on the BIM Task Group (BSI, 2013) The PAS1192-2 standard is limited to the description of information exchange specific to BIM whereas, the BS1192:2007 standard has a wider scope and provides guidelines for delivering all the information throughout the entire lifecycle of the project. The BIM Task Group stated the aim of PAS1192-2 is to achieve BIM maturity level 2 (See Figure 3-11) by illustrating requirements for this level and developing the framework for applying BIM in an integrated working environment.

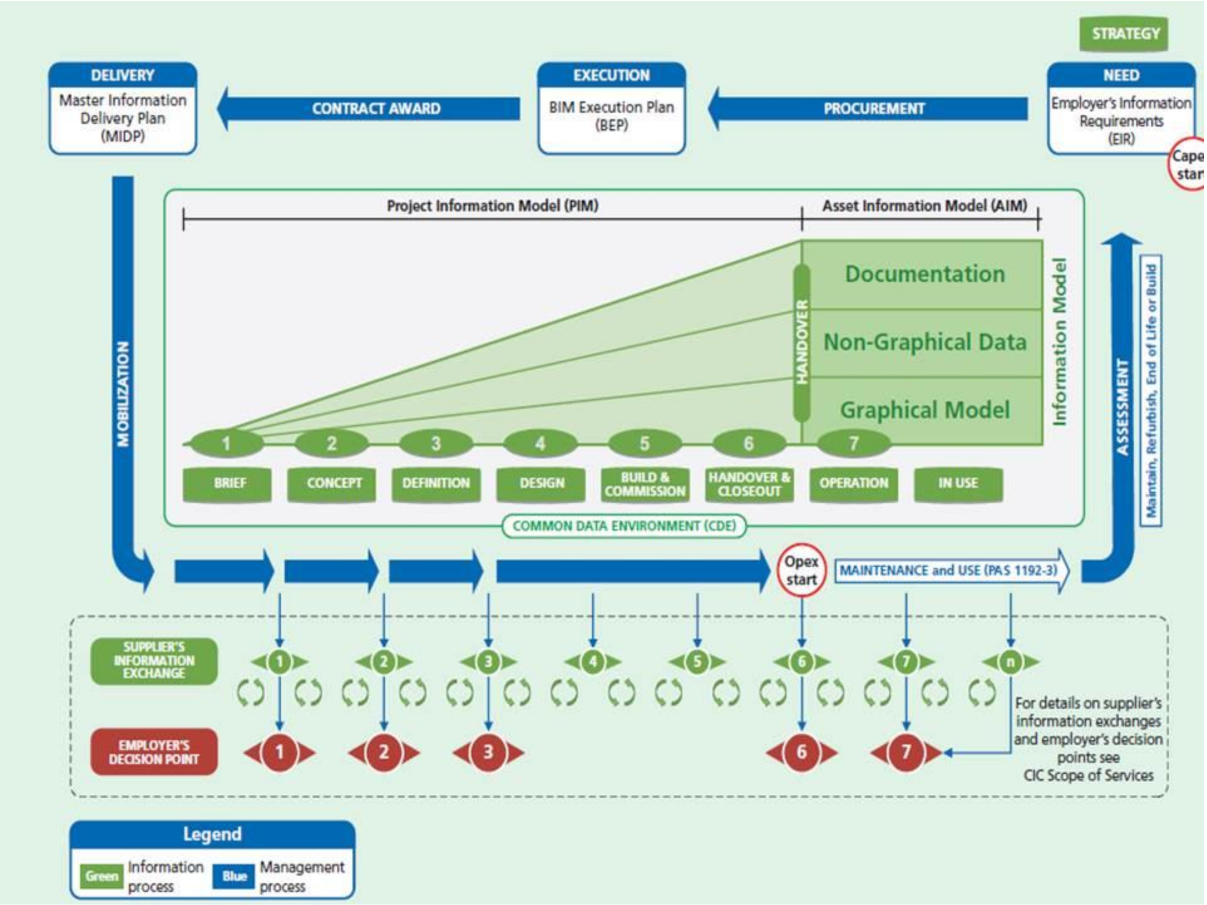


Figure 3-11 PASS 1192-2 Information Delivery Cycle Framework (BSI, 2013)

PAS1192-2 concentrated particularly on the deliver phase of information from determining requirement through to delivering of asset. The information delivery cycle as shows in Figure 3-11 starts from 'Need' box, where there is no pre-existing information. The Employers Information Requirements (EIRs) describes the information exchange and collaboration requirements, on the other words, EIRs determines which document and model require to be provided at specific project phase. As it has been stated in BIM Task Group Website, EIRs should be a component of tender document to contribute client's decision making at technical, management and commercial stages of the project. The Table 3-4 presented the contents of information which are covered in EIRs stage. After identifying the information requirement for project, the cycle is followed to BIM Execution Plan (BEP).

The focus of PAS1192-2 is mainly on the delivery phase of information, commencing from the determination of the requirement to the delivery of the asset. Figure 3-11 depicts the information delivery cycle. The 'Need' box is the starting point at which there is no pre-existing information. Information exchange and collaboration requirements are described by Employers Information Requirements (EIRs). The specific document and model that are needed at a particular phase of the project is determined by the EIR's. As stated in BIM Task Group Website, EIRs should be a component of the tender document to contribute to the client's decision making process at technical, management and commercial stages of the project. The contents of information covered in the EIR stage is presented in Table 3-4. Consequent to the identification of the information needed for the project, the BIM Execution Plan (BEP) is initiated. Based upon the requested information in the EIR, supply chain responses are carried out in the BEP stage. The BEP enables the supplier to confirm the supply chain capabilities by submitting to the client. Post Contract Award aims to facilitate management of delivery on the project by specifying the contents which are mentioned in EIRs.

Table 3-4 EIRs contents (BSI, 2013)

Information Management	Commercial Management	Competence Management
Roles, responsibilities and authorities of Stakeholders	Alignment of information exchanges, work stages, purpose and required formats;	BIM tender assessment details
Level of details	details of the expected purposes for information provided in models	details of the competence assessment which bidders must respond to

Data requirements for bidder's proposal for the model process	Schedule of any software formats	changes to associated tender documentation
Coordination and clash detection process	Setting out responsibility matrix	
Requirements for bidder's proposal for the management of collaboration process	Schedule of the standards and guidance documents used to define ne the BIM processes	
Security requirements for the project	Defining the changes to the standard	
Health and safety requirements		
System performance plan		
Compliance plan		
Delivery strategy for asset		

Information delivery production is the next step in the information delivery cycle. BSI (2013) pointed out that at this stage there is significant mobilisation to ensure that the information management plans of the project teams fulfil the design goals prior to the commencement of the design. In this stage project delivery team should give consideration to review that all necessary documents have been set up and approved, information management process are in place, the design team have the proper abilities, skills and adopted technologies to enable information management in accordance to PAS1192-2 protocols. The process of delivery information management is followed by reviewing the information at each exchange action to make sure that the information is unambiguous and accurate. The PAS1192-2 emphasized on accessibility of creation, sharing and issuing of information in a timely and lean approach and has recommended Common Data Environment (CDE) as an enabling factor. CDE represents single source of information which is used for collecting, managing and documenting information. The CDE covers all graphical models and non-graphical information for all the stakeholders of the project. Providing a single source of information simplifies collaboration between all construction disciplines and contributes to reduce the mistakes and duplication. As a complement to the PAS1192-2, a forthcoming PAS1192-3 guideline is to be provided, to support information accessibility, integrity and exchange in the operational asset management phase.

3.3.3 Information Delivery Manual (ISO29481)

The Information Delivery Manual (IDM) has been developed with the aim of providing an integrated construction cycle workflow by identifying the processes undertaken in the construction lifecycle. The components of IDM principal are exchange concept, exchange requirement and process map as it presented in Figure 3-12 (Karlshoj, 2011). IDM emphasised on IFC schema as a fundamental element to take-up BIM and exchanging information between various BIM users (AEC3, 2013). The IFC schema is created as a group of individual topics. Each topic signifies the overall idea for instance; structural analysis, structural elements, cost, material etc. Wix and Korlshoj (2010) asserted, IFC aims to support all business requirements at all project phases and this aid the industry to share and exchange information between organisation . On the other hand, it is important to determine which IFC type should be used to meet a particular requirement.

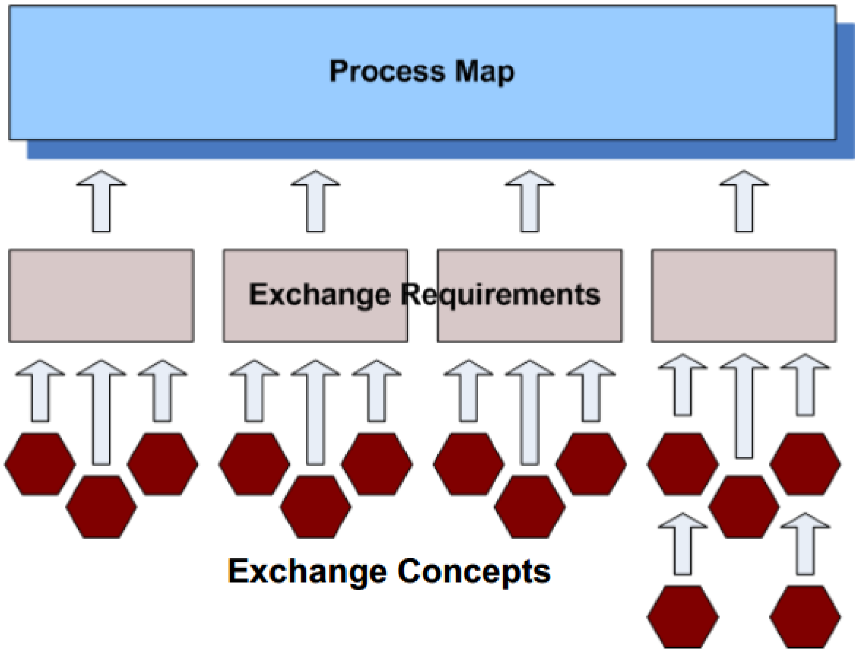


Figure 3-12 Principal Components of IDM (Karlshoj, 2011)

The components of IDM are exchange concepts, exchange requirements and process map. The connection between process and information model is determined as exchange requirement by the IDM protocol. The requirements of information process management are described in following questions; what is the information require to be created, who are the disciplines consuming and taking benefits from the information, where the process fit in and how the information could be supported by software solution (Wix and Korlshoj, 2010) and Figure 3-13 represents that in structural engineering processes, information models need to be defined within an exchange requirements to fulfil the requirements at each particular phase of the project.

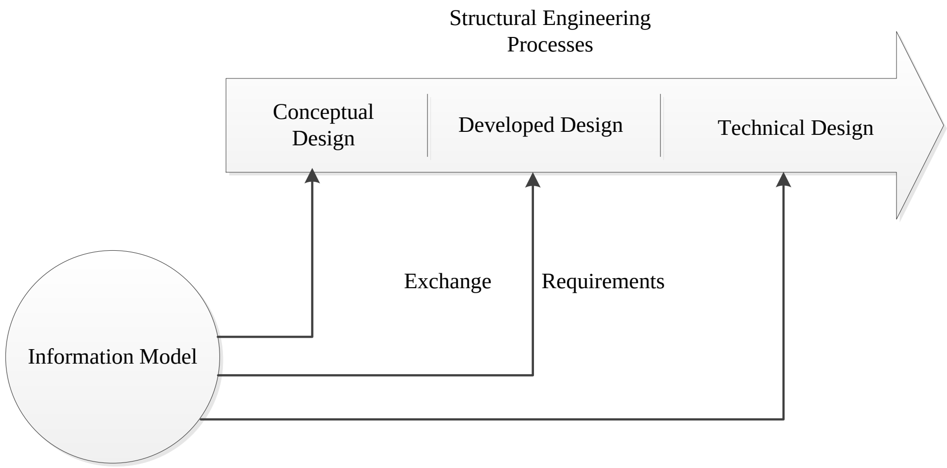


Figure 3-13 Exchange requirements in structural engineering process based on IDM concept

The exchange requirement specifies a set of processes that have been functioned by an actor to enable downstream processes that would be performed by another actor (Smith and Tardif, 2009). An exchange requirement is included three main sections as followings (Wix and Korlshoj, 2010);

1- Header Section: A header section delivers administrative information related to name, title, unique identifier which is allocated to an exchange requirement, date of creation/change of information, the person who is responsible for the creation/exchange, and the project phase for which the exchange is used

2- Overview: An overview provides the purpose and context of the exchange requirement. The purpose shall be recognised by an actor who should be aware of the exchange requirement achievement. Normally this actor would be executive user for instance, some actor who in acting in structural design management team.

3- Information requirement: The information requirement provides a set of information units which are essential for technical actions. Each information unit is broken down to more properties and attributes to describe each unit that is exchanged.

Figure 3-13 depicts the top layer of IDM as a process map that is related to process definition. The flow of activities will be determined within process map layer of IDM. On the other words, the information which is determined in exchange requirement layer could support the activities to develop a process. Wix and Korlshoj (2010) pointed out that for developing process map the following principal should be conducted by the BIM user; the boundary of extent of the information enclosed among the process should be established, The logical sequence of activities within process should be set up, The exchange requirements which support the activities should be identified and finally, enable reference process to be determine.

In the previous Sections (3.3.1, 3.3.2 & 3.3.3) the key points of three key available BIM workflows for structural engineering information management purpose have been discussed. Literature related to various BIM workflow tiers have been presented in these sections, and several BIM workflow options and their contribution of those tools towards information management have been explained. As discussed in section 1.4, the second objective of this study was to critically analyse the role of BIM in enhancing structural engineering information management. Therefore this section identified the key BIM workflows domains and recent tools that are available for structural engineering information management. The findings in this section contribute to this research in developing the second tier of conceptual framework. The components of conceptual framework in first tier are workflows options which are available for structural engineering in the UK, and the different stages of BIM workflows that include input, exchange, evaluation and publish, in majority of the available workflows are identified. In addition to technology and workflow, structural engineering industry needs to prepare its human resources to employ available BIM technologies and BIM workflows. The following section will review the literature to identify state of the art literature in the course of human resource reediness for BIM implementation in construction design organisations particularly in structural engineering firms.

3.4 Human Resource readiness for implementing BIM

Many issues were faced by AEC organisations while implementing BIM. These are categorised into four types (Kiviniemi, 2011); technical issues (The dimensions of this aspect has been studied in section 3.2), legal issues (related to legal responsibilities of information content and status), business issues (including the allocation of responsibilities, roles and rewards) and human resources issues (related to concerns and resistance to change). The UK BIM Implementation strategy, stresses that although BIM overcomes the problems associated with design, the difficulties and challenges associated with its adoption cannot be neglected (BIS, 2011). This research has studied the technical and process aspects of BIM and due to time and cost limitations all aspects cannot be covered by this study. In the context of the readiness of structural engineering organisations to adopt BIM to increase the level of information quality this research has narrowed down its focus into human resource.

Yan and Damian (2010) conducted a survey on the adoption of BIM by the construction industry in the UK and US. The obstacles that they identified in their study were mostly related to human resource factors. Their participants mainly responded that the human resource training in the AEC organisations is the main barrier to the adoption of BIM in their organisations. The review of state of the art literature on human resource reediness for BIM implementation shows there are two main criteria; skills and opinion. Regarding human resource reediness for BIM adoption, Gu and London (2010) argued there are number of barriers which are lack of awareness, lack of training and hesitation to learn new concepts and technologies. Findings from the case study by Haron (2013) shows that success of any BIM implementation will depend on the skill and opinion of the people tasked with using the technology and processes. It can be finalised based on those researches (Gu and London, 2010, Haron, 2013), structural engineers readiness to implement BIM can be facilitated in recruitment and training levels to increase practitioners skills and knowledge about BIM technologies and workflows.

The BIM implementations in recent AEC industry era impact on roles and responsibilities of practitioners due to this; new roles and responsibilities need to be defined in recruitment practitioners. Kiviniemi and WIlkins (2008) stated that BIM adoption requires to define each stakeholders' roles and responsibilities. Deutsch (2011) suggested four BIM related roles and responsibilities namely BIM Modeller, BIM Operator, BIM Coordinator and BIM manager. BIM Modeller or BIM Designer is responsible to operate the BIM tools such authoring the 3D model, and extracting and preparing the design deliverables. BIM Administrator or Managers are responsible to manage, administrate and facilitate all the technical aspects of BIM which includes preparing the software to be used by the Modeller or Designer, troubleshooting software technical problems, monitoring and checking the accuracy of the drawings and 3D models, and preparing the 3D object libraries. As it can be seen many of those BIM roles are defined based on technical skills. Industry needs employees who can be a BIM leader in company and develop guidance for implementing right technologies and workflows. However, that company would be in risk when BIM leader left the company (Davies, 2014). As it can be seen many researchers tried to identified several BIM responsibilities however, the level of readiness of AEC industry human resources is not efficient to take those responsibilities.

AEC professional organisations are suffering from lack of adequate BIM trained employees (Becerick-Gerber et al., 2011). The abilities in utilising communication and collaboration technology and understanding of BIM process are suggested as key priority for recruitment and training approaches in papering human resources for BIM implementation in AEC organisations (Joseph, 2011). Many educator organisations try to provide BIM-oriented courses to prepare students in colleges and universities ready for employment in organisations who are interested in recruiting BIM talents. Table 3-5 presents some high rated BIM-oriented courses which are available in several colleges and universities. Training human resources for adopting BIM can be conducted in universities or in industry as internship. Peterson et al. (2011) studied effects of BIM training in universities on project management in real work environment. In their research it has been shown that using BIM in universities as assignment help project managers to simulate better real-world project conditions. Wu and Issa (2014b) suggested more partnership between educational sector and industry could be a solution to advancing BIM skills in AEC industry.

Table 3-5 Desired student learning outcome for college BIM education (Wu and Issa, 2014b)

	Case 1		**Case 2**	
Student learning outcome	Rating Average	Rating Rank	Rating Average	Rating Rank
BIM software application skill	4.46	1	4.15	1
Knowledge of BIM concept and literature	4.46	1	3.81	2
Understanding of BIM standards and interoperability issues	4.22	3	3.73	3
BIM internships and working experience	4.17	4	3.72	4

Network-based BIM model management knowledge	4.04	5	3.43	5
Understanding of BIM-facilitate green design	3.91	6	3.45	6
BIM-based capstone project experience	3.87	7	3.18	7

BIM talents acquisition is very critical for organisations to address the both BIM technology and BIM workflow challenges in BIM implementation in AEC industry. However there are very few companies developed strategic approach to address such impacts (Wu and Issa, 2014a). There is an intention for this research to collect the practitioners in structural engineering discipline to have deep understanding of their challenges in human resources readiness for BIM adoption and their recommendations for other companies who are interested in adopting BIM and acquiring BIM talented human resources.

3.5 Initial Conceptual Framework

The main concern of this study is contribution to practice by developing new knowledge. An initial conceptual framework for addressing structural engineering information challenges can be employed in this research to limit the scope of relevant information and identifying the key variables and relationships of variables. The initial conceptual framework as presented by Figure 3-14 was developed by reviewing the literature. Figure 3-14 presents the initial framework which has been examined from reviewing the literature. The framework of concepts, assumptions, expectations, beliefs and theories can be expressed to support and inform a research (Maxwell, 2005). The findings from chapter 2, contribute to this study that key information management challenges in AEC industry and structural engineering discipline are related to dimensions of information quality however the information quality in structural engineering discipline has its specific key dimensions. As presented in Figure 3-14 the key dimensions of information quality are identified and described in three categories; information accuracy, information interoperability and information accessibility. Structural engineering may work in a fragmented environment segregated from other design and construction disciplines, hence the information should be provided in an exchangeable format to be readable by other disciplines. In structural engineering information acquired from various disciplines should be updated on a day to day basis. The accuracy of contractor's implementation and success of bidding procedure rely on accuracy of structural drawings and reports.

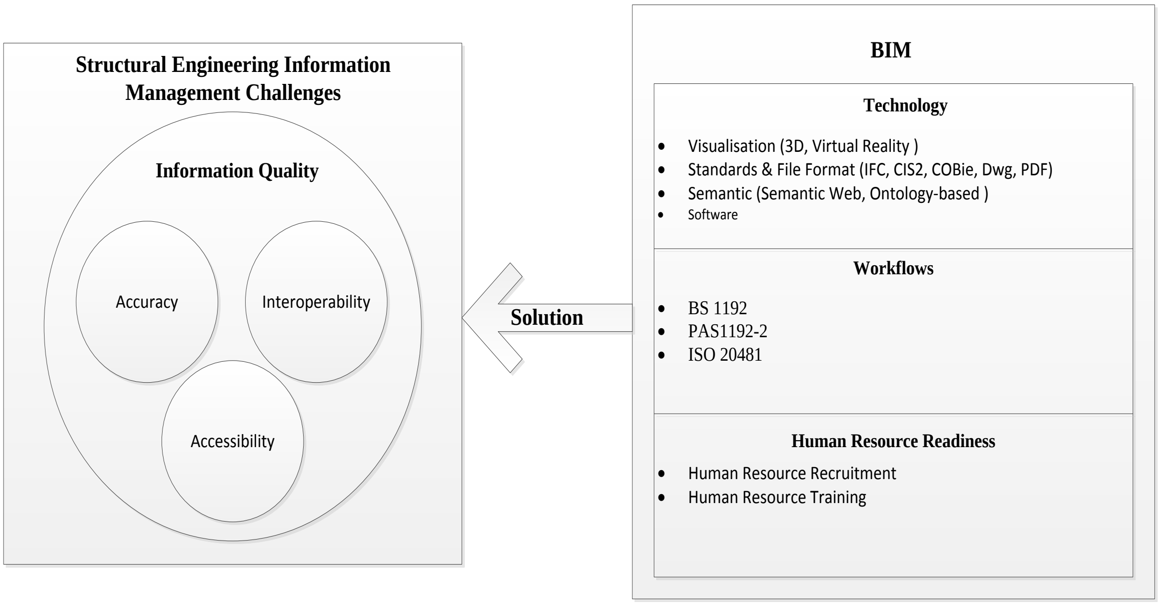


Figure 3-14 Initial Conceptual Framework

Conceptual frameworks can be relied on four key factors: boundary, Unit of analysis, concepts and relationships between concepts (Miles and Huberman, 1994). The boundary defined the research scope which limited to specific research focus, specific location and specific time. As already indicated in section 1.5, this research is narrowed down to information management in structural engineering discipline. Most of the challenges presented in the existing literature were faced by the AEC industry and construction sector, and insufficient references were found specific to the structural engineering sector. However, from the review of literature, starting from the broad concept of the AEC industry and then narrowing down the scope of the research helped reached the assumption of specific information management challenges faced by the structural engineering sector. These have been listed in the proposed initial conceptual framework. This research requires testing this assumption by a study of the real world in future chapters. The second factor that should be considered in developing conceptual framework is unit of analysis, which indicates exploring the target of the research. The initial conceptual framework in this research was developed on exploring contribution of BIM to address key challenges of structural engineering information management. As it is presented in Figure 3-14 technological, workflows and human resource readiness are the main domains of BIM that structural engineering organisations can consider before implementation of BIM in their companies. The review of literature shows that by considering key BIM domains the quality of information in the structural engineering discipline can be enhanced, however the industry needs to have comprehensive conceptual framework to show them available options in each BIM domains, the outcomes of adopting those options in information quality. From the current literature there is no evidence of the development of this type of a conceptual framework for the structural engineering discipline. Hence, this research collected secondary data from UK-based structural engineering organisations which have adopted BIM in their organisations or are in the process of adopting BIM (See chapter 5 & 6). The industry opinion contributed to this research to examine firstly, the key options and key factors in each of the BIM domains which are independent variables. Secondly, the relationships between key factors in BIM adoption and dimensions of information quality (dependent variables) are measured.

3.6 Chapter Summary

The previous chapter stresses that quality of information is a critical issue in information management in structural engineering organisations. The key dimensions of information quality in the process of structural design to produce graphical and non-graphical information have been specified and are information interoperability, information accessibility and information accuracy. This chapter suggested Building Information Modelling as a solution to increase the level of information quality dimensions. This research by review of the state of the art literature identified the factors for increasing the level of information quality in the choice of BIM implementation in structural organisations. These concepts are narrowed down into technological aspects, process aspects, and human resource readiness aspect. The technological contribution of BIM into recent visualisation capabilities, file format standards such as IFC and CIS2, Semantic and ontology engineering information management and software have been highlighted in this research. Recent BIM protocols such as ISO 20481, PAS 1192 and BS 1192 and also the importance of human resource training and recruitment have also been discussed in this research. Creation of the initial conceptual framework was required for designing the questionnaire for this research, the relationships between concepts and factors would help in the comprehension of the dependent and independent variables. The initial concepts and relationship between these are created by reviewing the existing body of knowledge. The interview result will aid this research to modify the initial conceptual framework by capturing the expert's voice in the UK structural engineering industry.

CHAPTER 4. RESEARCH METHODOLOGY

The purpose of this chapter is to provide relevant information and outline the methodology and approaches to be followed in order to achieve the research design. This chapter starts by a general introduction of the research philosophy, approach and strategy and discussed various research methods including mixed method research approach, the inductive research approach, case study research strategy, the survey data collection method and then the research design that was used to show the road map to the research. In the last part of this chapter the data analysis strategy was covered, which includes qualitative research analysis and quantitative research measure and analysis.

According to Fellows and Liu (2003), researchers require a systematic approach in order to investigate their aim and objectives. Therefore methodology is related to the choice of research which is conducted by particular researcher. Saunders et al. (2012) define research as a methodical interpretation and collection of data that is designed to discover the answers to particular questions. The understanding of the research methodology lies on the research concerns and methods of study.

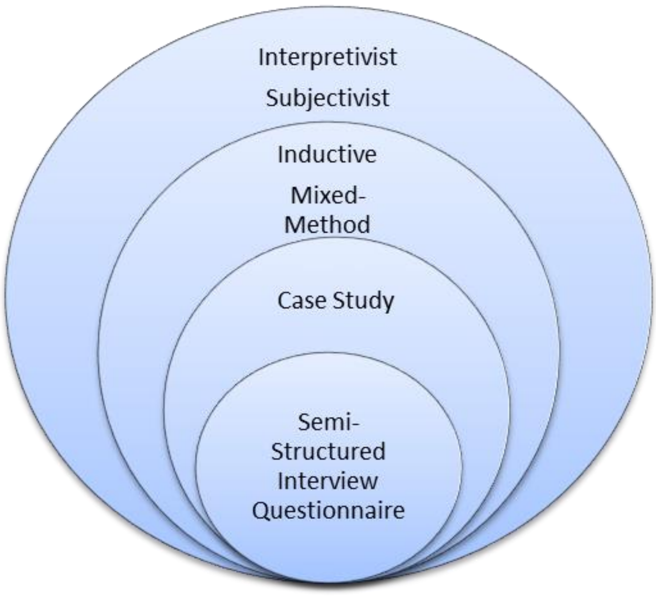


Figure 4-1 the research onion

This research adopted "*Research Onion*" (Saunders et al., 2012) methodology model. The research onion explains methodology from philosophical paradigm through to the research method, research approach, research strategy, data collection and data analysis techniques to make it clear to understand and conduct each layer as a particular research activity.

4.1 Philosophical Paradigm

The external layer of the research onion is the research philosophy. The philosophical paradigm represents the nature of individual phenomenon in the world and the relationship between phenomena and to the world (Guba and Lincoln, 1994). Applying the appropriate research philosophy would contribute to clarifying and understanding research design. Understanding the philosophical paradigm can shape the research layers. Saunders et al. (2012) examined three main aspects of research philosophy: epistemology, ontology and axiology. In the following sections the principal aspects of research philosophy have been introduced and the appropriate philosophical choices justified by considering to the nature of this particular research.

4.1.1 Epistemology

Epistemology is one of the fundamental elements of research philosophy and studies the possible methods to obtain the knowledge of social reality. According to Saunders et al. (2007) "*epistemology concerns what constitutes acceptable knowledge in a field of study*". Epistemology is classified into two comprehensive divisions by most authors, namely: positivism and interpretivism (Maxwell, 2005, Saunders et al., 2012) Positivism deals with observable phenomena and positive facts where the data in this thought is derived from logical experiences (Macionis and Gerber, 2010). Positivism epistemological paradigm typically applied in natural science to the study of social reality and beyond. The positivist researchers normally believe that the reality can be explained and measured independently from observers and their instruments (Myers, 2013). On the other hand, interpretivists undertake human creations and associate the subjective and inter-subjective with the world around them (Orlikowski and Baroudi, 1990). Interpretivist researchers assume that reality cannot be explained dependently from the observers' interpretations. Hence the elements which are build reality (dependent variables, independent variables and relationship between them) can be formulated by researcher and observers' interpretations (Myers, 2013).

4.1.2 Ontology

The ontological philosophical research paradigm studies the form and the nature of reality. Ontological thinking argues that the nature of reality can be divided into two main categories:

objectivism and subjectivism. Bryman (2004) described objectivism as being based on the fact that “social phenomena and their meaning have an existence that depends of social actors”. Conversely subjectivism is based on the view that social phenomena are created by the perceptions and consequent actions of social actors (Saunders et al., 2012).

4.1.3 Axiology

The epistemology and ontology focused on truth, however, axiology studies the values of the researcher. Axiology is a component of research philosophy which explains the judgments of value (Saunders et al., 2012). Axiology studies the value of researcher’s role in the entire research procedure and to answer this critical question that what is the credit and value of the result of this particular research. In the axiological research point of view, research could be undertaken in value-free or value-laden (J.Gonzalez, 2013). In the value-free research environment, the role of researcher does not add any credit or value to the result of the research and value-free is close to positivism school of thought. On the other hand, the researcher’s value influences the outcome of the research.

4.1.4 Philosophical Paradigm Justifications

This section highlighted the choices of research philosophical paradigm as an analytical framework for the current research. This research focuses on information management and information quality as phenomenon which is influenced by the actors (designers, design managers). In the information management environment in structural engineers, it has been assumed that every thought that researchers and practitioners bring to this knowledge depends on their interpretations. Therefore this research has been structured using interpretivism philosophy (See Figure 4-2). Interpretive researchers attempt to understand phenomena over meanings which are assigned by participants. Each of them is a different camera that takes a different image of reality.

In this research, structural engineers are social actors who are located within organisations and have job descriptions which prescribe their duties. They are part of the design structure since some other part of the design discipline reports to them and they, in turn, report more details to others. The structural engineers in each organisation might have different design opinions and different facilities (e.g. IT systems). In this research, information quality aspects are recognised as phenomena which are created by a designer's activities and, as such, the environment could have an impact on their activities when creating the phenomenon. *Information quality is the relationship between the user's interpretation and a model* (Moody et al., 2003). Therefore the ontological though of this study is close to subjectivism where structural engineers as social actors explain the reality and relationships between phenomena and their though is subjective. The result of this research which has obtained from social actors (Structural engineers), will be analysing by researcher. In other words researcher's understandings and interpretation of the phenomena and reality that social actors mentioned can be described as value-laden. And the result of the research depends on researcher's role in terms of analysis and presentation of results. Axiology stance of this research is close to value-laden axiological paradigm as it has been shown in Figure 4-2.

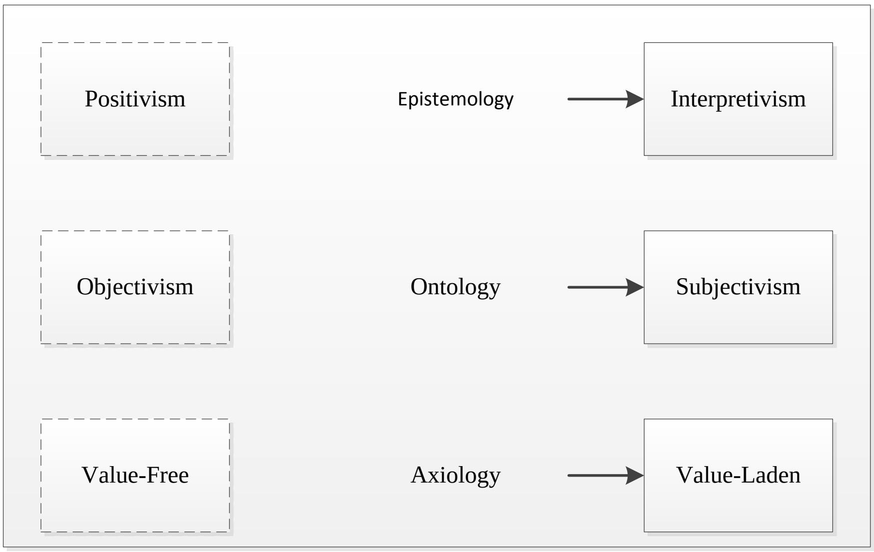


Figure 4-2 Philosophical Stance of This Research

4.2 Research Stages

This research investigated structural engineering requirements in the context of information management and tried to explore the contribution of BIM to address the key challenges in firms in the UK. The philosophical stance of this research is a key index for designing research stages. The position of philosophical stance leads this research to collect data from social actors who are involved in managing information in structural engineering discipline. The aim of this research is to propose a framework to guide structural engineers to adopt BIM and enhance their quality of information. The procedure of developing conceptual framework in this research begins with a review of the literature and proposes an initial conceptual framework from existing publications related to information challenges in AEC industry, structural engineering and available BIM in various domains (See section 3.5). The initial conceptual framework needed to be modified after incorporating and assessing secondary data from structural engineering information management stakeholders. The deep investigation and rich meaningful qualitative data were collected by studying two different cases that have been sourced from two structural engineering departments in two large UK-based organisations that have adopted BIM level 2. This research in qualitative data collection has adopted "non-probability" sampling which is appropriate for qualitative data collection and has a deep understanding of social phenomena. The content analysis technique was employed to analyse the transcribed text from semi-structured interviews. The research expected to identify information management challenges in greater detail, level of implementation BIM in those cases and explore the interviewee's opinion related to key criteria for BIM adoption and information quality outcomes. Survey method was employed followed by case study to achieve opinion of larger sample population from various organisational capabilities in the context of structural engineering. The questionnaire technique in this research seeks to explore critical challenges in structural engineering information management via measuring weight score. The relationship between key criteria of BIM adoption and information quality outcomes measured via factor analysis and multiple regression statistical techniques. The discussion between all findings from literature review, case studies and survey contributed to this research to finalise conceptual frameworks' key components and relationship between components. This section summarised the major research stages and expected outcomes of each stage. The following sections explained the alternative methods of research and justifications of applied methodology in more detail.

4.3 Research Method

Research methods are categorised into two distinct types: qualitative and quantitative (Saunders et al., 2012). There has been widespread debate by researchers regarding the merits of quantitative and qualitative approaches. It is often assumed that qualitative research relies on interpretive meanings and quantitative approaches drawn on positivist paradigms (Hughes, 2011). Although in some cases it has been claimed that quantitative approaches try to disassociate researchers from research procedures, on the other hand qualitative approaches have caused researchers to become more involved with the research (Winter, 2000). The qualitative method concerns the collection of written data and its subsequent data analysis instead of numbers (Denscombe, 2007). The qualitative method relies on well-grounded explanations and descriptions and implies both meanings and processes (Denzin and Lincoln, 1998). The major strength of this method mainly depends on underlying the meaning and explaining the phenomena. According to Bell (2005), the qualitative method takes full consideration of the individual perception of the particular phenomena rather than statistical analysis. Due to investigating individual perceptions in qualitative research, the sample for data gathering is often small but the data is rich and subjective (Creswell, 2009).

The quantitative research relies on an objective approach free of the human system and it activities in the context of the social and the natural world (Fellows and Liu, 2003). Quantitative research investigates the natural world by employing measurements and provides theories. It is concerned with the quantification of data and numeric analysis processes, whereby charts and graphs describe the results of the study (Bogdan and Biklen, 1998). In table 4, on the following page, the features and characteristics of both qualitative and quantitative research have been illustrated.

Table 4-1 features of qualitative and quantitative methods (Amaratunga et al., 2002)

Qualitative	Quantitative
Inquiry from the inside	Inquiry from the outside
An attempt to take account of the differences between people	Underpinned by a completely different set of epistemological foundations from those in qualitative research
Aimed at flexibility and lack of structure in order to allow theories and concepts to proceed in tandem	Are simply different ways to the same end?
The result are said to be, through theoretical generalisation, “deep, rich and meaningful”	Involves the following of various states of scientific research
Inductive - where propositions may develop not only from practice, or a literature review, but also from ideas themselves	The results are said to be “hard generalizable data”

An approach to the study of the social world, which seeks to describe and analyse the culture and behaviour of humans and their groups from the point of view of those being studied	

From the debates under the research method school of thoughts, it is highlighted that both qualitative and quantitative methods have their weaknesses and strengths (McGrath, 1982). The terminologies of reliability and validity are recognised as indexes of qualitative and quantitative strength (Golafshani, 2003). Reliability is about replicability and accuracy of the techniques and proceedings and the basic question in the centre of reliability is: would the same result be achieved by repeating the research? The validity asks the level of success that the research has actually achieved, what it set out to achieve and the basic question is: does X really cause Y? (Kirk and Miller, 1986, Emerald, 2012). According to Abowitz and Toole (2010)"combining quantitative and qualitative approaches in research design and data collection however should be considered whenever possible. Such mixed-methods research is more expensive than a single method approach, in terms of time, money, and energy but improves the validity and reliability of the resulting data". Next section explains the reasons for adopting mixed-method research in this thesis.

4.3.1 Research method justification

Construction is principally a "social" procedure (Abowitz and Toole, 2010) and this research can be considered to be an application of Building Information Modelling to the structural engineering design information management process. This is further to show that humans and designers play key roles in all aspects of building design and construction processes. This research adopted mixed-method approach for data collection (See Section 1-2) firstly qualitative data collection and then followed by quantitative data collection. Therefore, this research has been designed into two main steps; firstly, to define the key factors that affect information management as a phenomenon in structural design as a human activity in the integrated IT environment. In the first step, the research requires deep investigation and achieves rich and meaningful results; hence, the first step of study in this research relies on qualitative data collection and data analysis concerning the opinion of participants who were involved in the UK structural engineering discipline. In the second this research adopted quantitative data collection method (See Section 1-2). The aim was to measure the interaction of each key factor on the level of information quality and test the conceptual framework which is developed by reviewing the literature and has been modified by both qualitative and quantitative data analysis. This step of this research relies on the ranking of each key factor and adopts the weight of impact of each of factors.

4.4 Research Approach

There are two well-known research approach alternatives: deductive and inductive. Deductive research is more dominant in natural sciences, where most of the explanations related to the phenomena are presented through natural laws. Deductive research approach often starts from general to more detailed scope. In deductive approaches, researchers first of all complete a literature review to create and understand a problem. Figure 4-3 shows in deductive research approach, a hypothesis or theory is assumed and afterwards research will test the hypothesis to develop a theory (Saunders et al., 2012).

On the other hand, in inductive approaches, researchers state the problem and then collect the data to develop a theory based on data analysis. Inductive approach starts with particular observations of phenomena to broader generalization and developing theories. Figure 4-3 shows that in inductive research approach, theory is developed based on data collection and empirical generalization. In inductive research approach theory will be acquired as a consequence of the data analysis (Saunders et al., 2012).

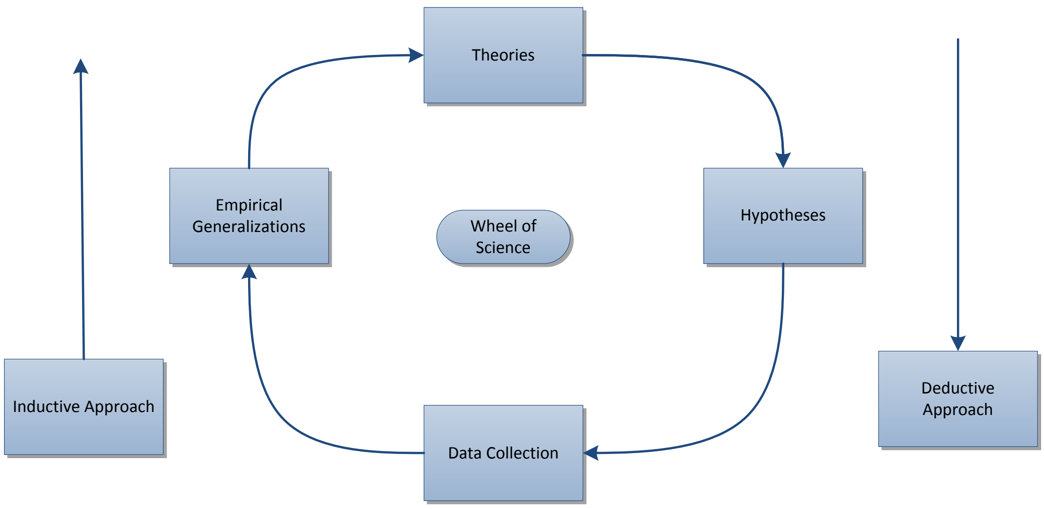


Figure 4-3 Wheel of science

This research firstly tried to determine the problem and review the current solutions in the literature for the problem which is close to deductive research approach. the researcher looks to develop a conceptual framework based on data collection, which has in turn been derived from a problem statement and research questions. Therefore, the final theory will be structured on the basis of the interactions between researchers and participants. This research requires detailed view of the phenomena and concepts from individual actors in the real world and generalise the findings to a larger population which is close to inductive research approach. BIM implementation in AEC and structural engineering information management domain is novel concept and literature review showed there are several researches are on-going in the area. Therefore, this research adopted both deductive and inductive approaches to find the problem through reviewing the state of art literature and considered perceptions of the industry actors to determine the key issues and relevant factors and relationships between those key issues and contribution factors.

4.5 Research Strategy

Kant (1934) argued that "The scope of people's knowledge is limited to the area of people's possible experience". The adoption of the research strategy is related to the scope of the aim and objectives, the limitations of recent knowledge and time and the cost resources available (Saunders et al., 2009). Robson (2002) suggested three influential research designs, which are grounded theory, ethnographic and case studies. Grounded theory argues that researchers need to "seek to enter the field without theoretical preconceptions" (Robson, 2002). Therefore, grounded theory focuses on developing theories which are grounded in the involvement of individuals. However, this theory is often considered in fields which have not been identified and there is a lack of theory surrounding the phenomena. Ethnography on the other hand, was applied by Europeans in the late 18th century to identify the social cultures of other continents humans (Geertz, 1977). In ethnography study the observation of the researcher can be focused on the field of humans in societies with the aim of understanding their cultures in such a way that minimises the amount of bias in the data. Robson (2002) described case study as "strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence".

Action research is another research strategy which is mostly used in areas including social care, organisational behaviour and education (McNiff and Whitehead, 2006, Reason and Bradbury, 2006, Koshy, 2010). In action research, researcher has this opportunity to participate in the research process as a collaborator rather than being subject of it (Denscombe, 2010). The co-operation of employers in targeted organisations plays very important role to the success of action research (Remenyi et al., 2005). Although action research can potentially aid this research to obtain valuable data by involving the researcher directly in the process of information management in structural engineering organisations, it is not a suitable strategy in comparison with case study research. Firstly, action research require considerable amount of time for researcher to be involved in whole process of information management in structural engineering organisation. Secondly, this research seeks to examine evidence in the real world from users of information system and experts who are involved in structural design and information management procedure within organisation rather than researcher's observation. In the following paragraph case study and survey approach, which are adopted as two main research strategies in this thesis, are discussed.

According to (Yin, 2014), a case study is mostly appropriate when research questions are of the "how" and "why" type. Therefore, for deep exploration of the context of BIM in structural engineering organisations, this research needs cases that have utilised BIM tools for integrated design procedure. It must evaluate such organisations in terms of BIM integration and communication tools in order to compare the outputs in the course of level of accuracy, interoperability and accessibility. A case study can be conducted to meet research requirements by using single or multiple approaches. According to (Yin, 2009, Yin, 2014), case studies can be categorised in four types; 1- Single-case holistic, 2- Single-case embedded, 3- Multiple-case holistic and 4- Multiple-case embedded. Single-case often is considered to observe and investigate a phenomenon that few have experienced and is appropriate when a well-formulated theory needs to be tested. Multiple case studies increase the robustness of generalisation to large populations and strengthen the research outcome by utilising various resources and replicating the research issues.

Survey is another well-known research strategy in business and management areas. Survey provides this opportunity to collect large quantities of data and evidence. Some PhD thesis might adopt survey as an effort to support theories (Remenyi et al., 2005). Survey research strategy often adopt questionnaire as a data collection technique. Questionnaire might be adopted when large number of respondents is located in many locations, when questions are understandable for respondents to read and social climate allow participants to respond full and honest answers (Denscombe, 2010). Next section discussed the reasons for adopting case study and survey for research methods.

4.5.1 Research Strategy Justification

Li et al. (2015) reviewed most of the research papers in information and communication technology in AEC industry. The most common research methods for those papers are including; case studies (26%), surveys (19%), interviews (10%), and prototype models (10%). Contractors (53, 37%) have received most of the attention of researches compared with other AEC disciplines. Structural engineering sector has been adopted as a focused area of information management in this research to propose a conceptual framework for the adoption of BIM to increase the quality of information in firms. The developing of conceptual framework need the involvement of structural engineers, BIM specialists and design managers who have experience of using BIM to improve information management performance. This research needs multiple sources of evidence for data collection. The aim is to investigate the quality of information of existing BIM tools used in the design phase and develop a set of guidelines for the industry. The outcome of this research is as follows: firstly, provide the key challenges that structural engineers face in managing the information; secondly, identify the existing support of BIM to structural engineering information management. Thirdly, explore the relationship between key information management challenges and existing BIM support factors. Finally to propose a conceptual framework for the first and last research objectives, the research seeks to ask the questions from cases in order to cover the contextual understanding, as it is found to be pertinent to the phenomenon under research.

This research triangulated various approach to the investigation of research objectives due to enrich confidence in presenting findings. There are different types of triangulation approach as; data, theory and methodological triangulation (Bryman, 2007). This research adopted data triangulation and mixed method triangulation. This research adopted qualitative and quantitative data collection approaches over various sampling strategies. Moreover, this research adopted case study and survey for collecting data. Mixed method triangulation allows this research to have evidence from multiple sources. In the case study stage, this research studied two cases (the design departments of two construction and infrastructure companies) and provided an opportunity to achieve access to different experiences in the case of using BIM tools in order to understand the key challenges of information management and BIM contributions. Survey method has been adapted to achieve a wider and more comprehensive view of information management challenges and BIM contributions in different structural organisations.

4.5.2 Case Study Design

Yin (2014) established five components for case study research design, they include; 1- case study's questions, 2- propositions, 3- unit(s) of analysis, 4- the logic linking the data to the propositions and 5- the criteria for interpreting the findings. The first components discusses the form of the questions for instance, "how" and "what" in respect of achieving the research objectives. The second component of case study research design describes the intension of researcher's interests which is planned to be examined within the research scope. The unit of analysis (third component of case study research design) defines individuals who stand together to established "case(s)" and relevant questions with logic attentions will be collected from those individuals. Identifying unit of analysis can limited case study questions and propositions. Different research questions might point to different unit of analysis. The fourth component refers to research discussion where findings of case study will be linked to research objectives and research questions. The final and fifth component of case study design defines criteria for statistical estimation for interpreting case study's findings. According to Yin (2014) the first three components (research questions, propositions and unit of analysis) lead research design into identifying data collection. And the last two components (linking data to proposition & criteria for interpreting case study's findings) link collected data to interpreting the findings.

The case study method is conducted in this research to address four objectives as defined in Section 1.4. In order to achieve research objectives three key research questions are considered to be addressed in this thesis as shown in Figure 4-2. The purposes of these research questions are to identified challenges in structural engineering organisations and examine key contributions of BIM to address those challenges (information quality). Structural engineers, BIM managers and design managers are involved in day to day using information management system. Therefore, this research targeted these participants who are working in two multidisciplinary construction organisations. The targeted organisations are leaders in adopting BIM and novel technologies in the UK in their information management systems. The targeted participants have sufficient experiment from their previous and particularly current projects to respond to the designed research questions (See Table 4-2). The findings from both cases can be duplicated or compare to each other to obtain robust conclusion in this research.

Table 4-2 Research questions and Unit of Analysis

Research Questions	Participants
1-What are the key challenges in structural engineering information management within UK?	Structural engineers BIM Managers Design Managers
2-How BIM is implemented in UK-based structural engineering organisations currently?	Structural engineers BIM Managers Design Managers
3-How can BIM contribute to key information management challenges in the structural engineering organisations?	Structural engineers BIM Managers Design Managers

According to Yin (2014, P 50) There are four types of case study; single-case holistic unit of analysis, single-case embedded unit of analysis, multiple-case holistic unit of analysis and multiple-case embedded unit of analysis. Single case studies have some disadvantages in terms of generalization of the findings from a single case however, multiple case study can improve the internal validity of the findings and conclusion from multiple evidences (Voss et al., 2002). As illustrated in Figure 4-4, there are subunits embedded in the unit of analysis for both two cases in this research. The participants are experts who are able to respond to the research questions in the context of information management within their current projects in their organisations.

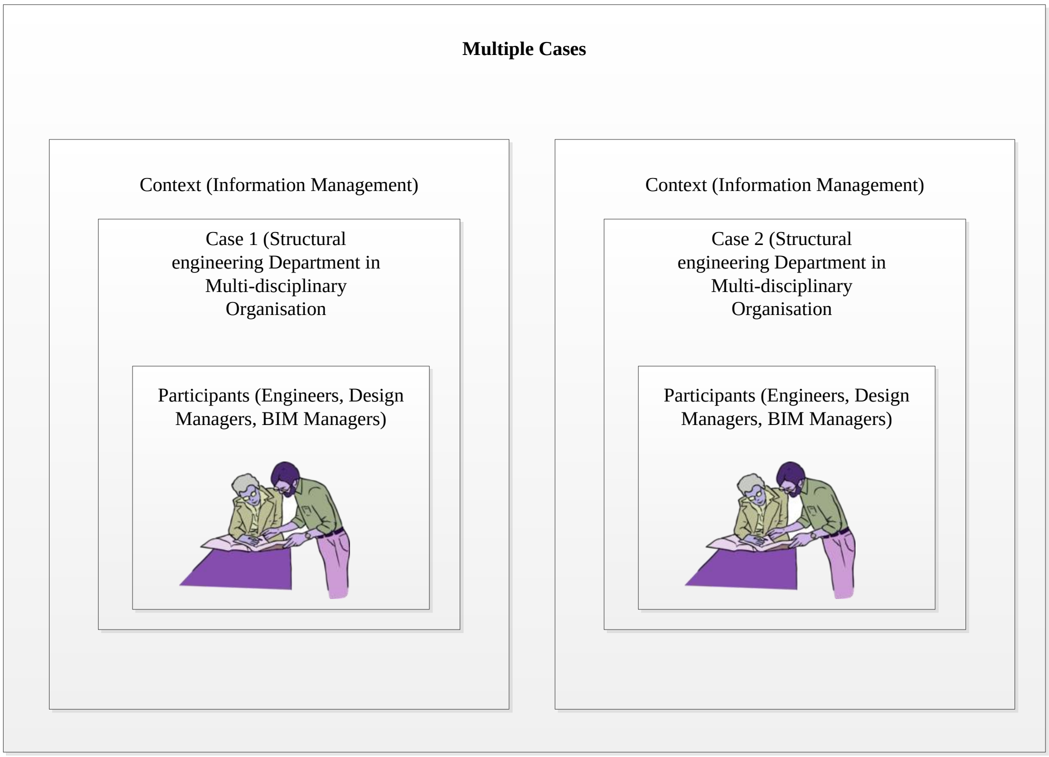


Figure 4-4 Case Study Design

Single case study is often employed to explore samples that are limited and difficult to generalise large populations. Therefore having at least two cases can contribute to credibility of the research results (Yin, 2014). This research adopted two cases as stronger evidence of findings and conclusions may be obtained due to replication. As shown in Figure 4-3, this research focused on two structural engineering departments in multi-disciplinary construction organisations in the UK. The analysis includes outcomes about information management in their current design projects. The results from the two cases was sufficient for this research to achieve rich and reliable data from experienced participants who are working in structural departments and who have years of experience in adopting BIM in the context of structural engineering discipline. In this research, the results of the two cases provided ample opportunity to compare data from different organisations and to understand the phenomena through achieving saturation and repetition of data In this research, case 1 is a structural engineering project in a structural engineering department in the organisation A. Organisation A is a world-class infrastructure and construction services organisation operating across the construction and infrastructure lifecycle. Teams of designers, planners, engineers, builders, project and facilities managers, analysts and consultants are working with their clients and partners to fund, design, deliver, operate and maintain infrastructure efficiency and safety.

This research focuses on the company's design office in the north west of England. Case 2 is also structural engineering design project in a structural engineering department in the organisation B. Organisation B Founded in 1946 with an initial focus on structural engineering, they first came to the world's attention through structural design and since then its work has grown the company into a multidisciplinary organisation. The company's portfolio today is broad and wide and their work goes beyond buildings and infrastructure. They have also developed a range of proprietary computer modelling tools, which they sell around the world. They have over 90 offices across Europe, North America, Africa and South East Asia, having tripled in size in the last ten years, and now employ over 11,000 people worldwide. However, this research focuses on the design office in the UK.

The qualitative data collection and analysis of this research is focused on context discovery, based on semi-structured interviews. This research adopted qualitative interview to build in-depth analysis based on details and richness rather than on statistical logic. As a result this research adopted two different cases out of which 12 interviews were solicited. Table 4-3 shows the demography of the participants in two different cases who were involved in qualitative interview data collection.

Table 4-3 Demography of interview participants

Participant Code	Case Study	Role	Years of experience
SSE1	Case1	Senior Structural Engineer	8
SSE2	Case1	Senior Structural Engineer	14
DM1	Case 1	Design Manager	12
SSE3	Case1	Senior Structural Engineer	14
SSE4	Case1	Senior Structural Engineer	9

BM1	Case1	BIM Manager	8
SSE5	Case2	Senior Structural Engineer	7
SSE6	Case2	Senior Structural Engineer	9
JSE7	Case2	Junior Structural Engineer	2
SSE8	Case2	Senior Structural Engineer	17
DM2	Case2	Design Manager	12
BM2	Case2	BIM Manager	15

Survey data collection is added in sequence to the case study to increase representation of larger population. Mixing qualitative case study method with quantitative survey (questionnaire) method can establish richer and stronger evidence when compared with single method alone (Yin, 2014, P 66). The focus of qualitative case study was on structural departments in large organisations which have capabilities in terms of budget and human resources to adopt BIM. However, this research required an exploration of the challenges and key consideration of small and medium structural organisation with different budget, capabilities, human resources and organisational structure in the context of adopting BIM and information quality. Therefore, quantitative data was collected via questionnaire from different participants in different structural organisations to provide more robust results for this research. In the following sections the techniques that have been used in this research to analyse both qualitative and quantitative data are presented in detail. The next section discussed the data collection technique that was adopted in this research to collect and analyse qualitative data in the case study methods.

4.6 Qualitative Data Collection and Sampling

There are two important concepts behind collecting data. The first one data sources and second is the method for generating results from those sources (Mason, 1996). The data gathering for the interpretivism research paradigm is a communication procedure between the researcher and the participants (Fellows and Liu, 2003) The key factor of the data collection technique is the nature of the request and the data required in regard to a certain setting or context (Naoum, 2013). Therefore, different techniques might be appropriate to different methods and inquiries. This research identified people as data sources due to their knowledge, evidence and experience. However, there are many approaches for generating data from those people, such as interviews, questionnaires and observations (Saunders et al., 2009). As discussed earlier, the method of this research is mixed-method, implying a method which could collect understandings, opinions, interpretations and ideas of people who have been involved with construction analysis and design. Mason (1996) suggested four techniques for data gathering in interpretivism research: interview, observation, the use of documents and the use of visual data. However, the combination of personal interviews and a questionnaire was suggested by Naoum (2013) as the method that offers the best technique for understanding a participant’s opinion.

The epistemological position of this research suggests that the logical way to generate data is by interacting with experienced people. This research seeks to generate data from those people’s experiences in their current or past organisations, how they interpret the relationship between BIM tools and structural engineering design can improve the level of information quality regarding the development of the BIM concept. This research in the first step of the data collection process utilised semi-Structured interviews to collect qualitative data. The researcher conducted in-depth investigation into the issues and expected explanations and descriptions to match the key elements derived from the interviewees. The interview was deigned to allow the participants to exercise total control over the process in order to prevent bias as much as possible. The researcher prepared some questions for the interview and interviewees are free to mention their opinion in more depth when essential.

For conducting a piece of qualitative research the number of interviews is often a dilemma for researchers. The answer is dependent upon methodological aspect of research and the nature of research questions. Therefore to decide how many qualitative interviews is enough the researcher has to explore the purpose of his study by taking into consideration to this fact "*saturation is central to qualitative sampling*" (Baker, 2012). This research in qualitative data collection has adopted "non-probability" sampling which is appropriate for qualitative data collection and understands the deeply social phenomena. The interviewee's have different background, years of experience and position in organisations (See table 4-3) and the central of qualitative sampling in this research relied on saturation of the responses. The number of interviews was continued to 12 when the researcher achieved saturation point, due to which the last interviewee's responses were merely a repetition of the previous interviewees.

4.6.1 Qualitative Data Analysis Technique

This research adopted "content analysis" (Robson, 2002) as a technique to enable the researcher to identify keywords and the meaning of text in the context of information management challenges. According to Bryman (2004), content analysis is a technique "for the analysis of texts that seeks to quantify content in terms of predetermined categories and in a systematic and replicable manner". The qualitative content analysis can provide codes for the data; those codes can be developed from the classification of texts into topics, themes or concepts. The contents came from communication between researcher and experts so that this research could apply qualitative content analysis in order to study the meaning of communication. Holsti (1969) classified content analysis into three fundamental categories: 1- Formulate inferences about the antecedents of the texts, 2- Describe the characteristics of the communication and 3- Describe the effect of the communication.

As has been mentioned before, interviews with experts were employed to determine the key challenges of interoperability during the design phase. Qualitative data analysis in this research used NVivo 10 software to collect, manage and represent the interview findings to achieve meaning. At the initial stage of the qualitative data analysis, the interviews were transcribed from an audio format into text for analysis and in the next stage the collected data was categorised into meaningful classification. The key words scanned from the text collected from expert interviews were used for the analysis based on the research's questions, aim and objectives. The next section discussed quantitative data collection and analysis techniques which are adopted in survey research method.

Through the case study this research expected firstly, to explore more data about challenges in the context of UK-based structural engineering organisations. Secondly, the case study is expected to investigate the level of BIM adoption in UK-based structural organisations.

Finally, the impact of implementing BIM and information quality is also expected to be examined. The outcomes contribute to this research to identify the conceptual tags of final conceptual framework. The conceptual tags are the key criteria that structural engineering organisations need to consider to adopt efficient tools, workflows standards and strategies for human resource readiness, to enhance the quality of information. However the results from case study alone cannot be the only evidence to support the conceptual framework. The case study collected data only from large structural engineering organisations with specific capacities. Therefore the survey study employed after the case study collected data from other structural engineering firms with different capabilities and discussion between findings from case study and survey creates strong evidence to support the conceptual framework in this research.

4.7 Quantitative Data Measurement and Analysis

This study used a questionnaire as a tool to obtain the understanding of a sample population in the UK structural design industry regarding information management challenges and relationship between implementing BIM and information quality satisfaction. Data collected from the questionnaire survey was analysed using a statistical analysis technique. Statistical techniques allow the researcher to elicit data from a larger geographical population in a shorter possible time in comparison with the semi-structured interview technique. In addition, this technique allows the participant to reply to the questions at their own convenience.

4.7.1 Sampling Strategy

Sampling has an important role while a survey is conducted on a product or situation to capture the voices of the population. Populations and samples are the basic factors of statistics. Often a set of individuals of that population will be investigated and that set is called a sample (Isotalo, 2009). Random and non-random samplings are the two major forms of sampling. Random sampling is considered if every single piece in the population has the same chance of being selected whereas in non-random sampling not all individuals have the same probability of being chosen (Lawton and Bass, 2006).

Non-random sampling is applied to this study due to the research limitations, such as cost and time, which did not allow the researcher to apply random sampling. According to these limitations, the researcher selected the items of population that have experience and knowledge related to the research area. The targeted sampling was purposive. Purposive sampling is a technique to select samples that are willing to participate and have experience and knowledge that is related to the research domain. The targeted participants for the questionnaire were in pursuant to the following criteria:

1- A designer/design manager team in the structural industry.

2- Relevant experience of integrated design projects.

3- Relevant experience of implementing at least BIM level 2 and ICT in structural engineering information management.

The general idea about sample size is “larger sample, better sample” however; there are always limitations for researchers to collect data from whole population. There are number of recommendations for interpretivists and the researchers who collect their data from human interpretation to make their sample size reliable. The sample size should be optimum to obtain specific context of data. The optimum sample size can represent a total population and the result can be generalised to that population with minimum error. According to Takim et al. (2004) AEC industry is non-supportive in responding to questionnaire, therefore 20% to 30% response rate is acceptable for analysis. The sample of questionnaire in this research was drawn by selecting relevant participant through LinkedIn Platform. LinkedIn is a platform where different professionals group gather to share ideas and network. The web-based questionnaire was sent to 300 respondents (structural engineers, BIM managers, design managers and researchers all available on LinkedIn) whose Linked In’s profile page meets participants’ criteria. 125 responds were received within two month. The respond rate 41% was achieved.

Questionnaire questions can be categorised into two groups: closed or open-ended. The closed question option offers respondents a group of pre-set response choices, i.e. multiple choices. In open-ended questionnaire respondents have the liberty to respond in their own words and are not restricted to the pre-set choices designed by the researcher. Closed questions may be simpler to convert to the numerical format but the questionnaire in this research was designed to use both close-ended and open-ended methods due to the deep understanding of issues needed in the semi-structured questionnaire survey and also in line with the philosophical stance of this research.

Piloting the questionnaire is emphasized to refine the questionnaire (Leung, 2001). This strategy could help to identify unanticipated issues with the questionnaire such as; structure, wording etc. In addition it reveals whether participants understand the questions and the questions would yield useful answers. In this research, the draft of the questionnaire were presented to three experts in the BIM education and who had years of experience in industry to leave comments and suggestions. Those experts left comments related to re-wording the important words for participants, made the layout more attractive, removed redundant queries and they described key terms in the introduction. Next section discussed various quantitative analysis tests to identify the most appropriate statistical test for this research.

4.7.2 Quantitative Data Analysis Techniques

In the questionnaire survey analysis the characteristic of data that is collected is very important in the sense that the type of data can lend themselves to different types of analysis. The appropriate method of analysis makes final results to be more valid (E.Saris and N.Gallhofor, 2014). There are four types of data in questionnaire survey. The first type is "nominal data" which can be coded as numbers however, those numbers has no real meaning. For example in this questionnaire job role, education qualification, size of organisation and type of organisation are nominal data. The second type of data is "ordinal" data. Ordinal data can be sorted in order of sequence however; there is no real numerical meaning head of order. For example in this questionnaire some responds are coded 1= not a challenge at all, 2= it's not a challenge, 3=Neutral, 4= critical challenge and 5= very critical challenge. The third type of the data is "interval data" which the distances between numbers have meaning however zero point does not have meaning. The fourth data are "ratio data". The ratio data is also called numerical data. The distances between intervals data and zero point have meaning for instance, height and weight. All the data that this research through questionnaire has collected are **nominal** or **ordinal**.

The second characteristic of survey is to identify variables. In statistic science there are two kinds of variable, they are independent and dependent. According to Fink (2003) *"A variable is a characteristic that is measurable".* Height and weight can be categorised into variable and each person have specific number for his height and weight however, some variables are based on human interpretation for measuring. For instance in this research survey, information management challenges are measured on a scale from not a challenge at all to very critical challenge. Pallant (2010) argued that independent variables are applied to explain or predict the characteristic of dependent variables. In this research the quality of information in structural engineering organisation is dependent variable. This variable has some sub-variables which are identified by literature (accessibility, accuracy Interoperability and security). In the next chapter via case study this research identifies more critical sub-variables for quality of information. The appropriate technological BIM tools, appropriate BIM workflows and appropriate human resource readiness strategy for adopting BIM are the independent variables in this research.

The second characteristic of data in questionnaire is parametric or nonparametric data. In general parametric data can be assumed while the data is normally distributed. The normal distribution is really significant continuous probability distribution. Distribution shows *"the frequency of occurrence of the values"(Fink, 2003).* The wide varieties of statistical techniques are classified into two main types: parametric and non-parametric. It is assumed in parametric statistics that the underlying distribution of scores in the population is normal. In the initial part of the quantitative data analysis of this research the descriptive statistics will be conducted through a central tendency of observed data sources, however, descriptive data analysis will not be the final quantitative analysis in this research. Descriptive statistics is a well-known technique of analysis but has its advantages and weaknesses depending on the analysis objectives.

4.7.3 Descriptive Statistics

Descriptive statistics often uses numerical and graphical manners to present data findings. The main goal in descriptive statistics is to summarize the sample by presenting into graphs, charts and histogram. The descriptive statistics is not relied on probability theory. The core of descriptive statistics is: mode, median, mean, variance, and standard deviation. The mean consider the average of observations and symbolised by $\bar{X}$. The formula for calculating mean is:

Equation 1- Mean Equation

$$\bar{X} = \sum \frac{X}{n}$$ (Lawton and Bass, 2006)

Where : X is each individual observation n is the total number of observation

The mode considers the score of factors that most frequently happen, however, this study looks for weight scores and mode does not have an exclusive weighed score by reason of there being more than one mode among a data set. Median is not concerned by the weighed scores of a data set although a mean is (Lawton and Bass, 2006). The standard deviation is *“a measure of the spread of the data around the mean” (Fink, 2003).* The standard deviation is symbolised by SD and the calculation depends on average distance from mean. The standard deviation squared is called the Variance. The formula for calculating standard deviation is:

Equation 2- Standard Deviation Formula

$$SD = \sqrt{\frac{\sum(X-\bar{X})^2}{(n-1)}}$$ (Lawton and Bass, 2006)

4.7.4 Parametric Techniques

Before starting statistical analysis, it has been emphasised by many authors (Fink, 2003, Lawton and Bass, 2006, Garth and Hallam, 2008, Gatignon, 2010) to check normality of data whether data are parametric or nonparametric. In general parametric data are assumed to be normally distributed. It means that the most value of data is distributed close to mean. Garth and Hallam (2008) argued that if the researcher is not assure about normality of data, it’s safer to assume those data are non-parametric. Garth and Hallam (2008) also expressed that the risk of this assumption is that the non-parametric tests are less sensitive; therefore the result would take smaller effect of missing.

Some statistical tests are based on assuming that data distribution of population is parametric such as T-test and correlation coefficient. The other group of tests are relies on non-parametric distribution assumption including; Kruskal-Wallis and Chi-square. After determining normality of data, the researcher would specify whether questionnaire look for measuring differences or correlation. The differences are will be measuring when there are two set of data and correlation is used when there are set of paired data. In the survey research, often the strength relationship between variables and the differences between groups are considered (Pallant, 2010). However, in some researches the interest is limited to the relationship between variables and there are a number of different techniques in that case.

In the following sections these techniques are described to have more clear understanding related to statistical tests available for analysing questionnaire survey.

4.7.4.1 Correlation test

Correlation is the technique that applies when the research is interested in exploring the relationship between two continuous variables. When the two variables are described numerically, correlation coefficient can be applied (Fink, 2003). The correlation coefficient has a range of +1 to -1. In correlation coefficient if we consider two variables Y and Z, which Y is independent variable and Z is dependent variable. +1 correlation indicates that the value of dependent variable growth by the same quantity for each unit growth in the value of dependent variable. Nevertheless, correlation -1 shows strong inverse relationship between independent and dependent variables and zero correlation specifies that there are no relationships between independent and dependent variables. Correlation can be described graphically by scatterplots (See Figure 4-5).

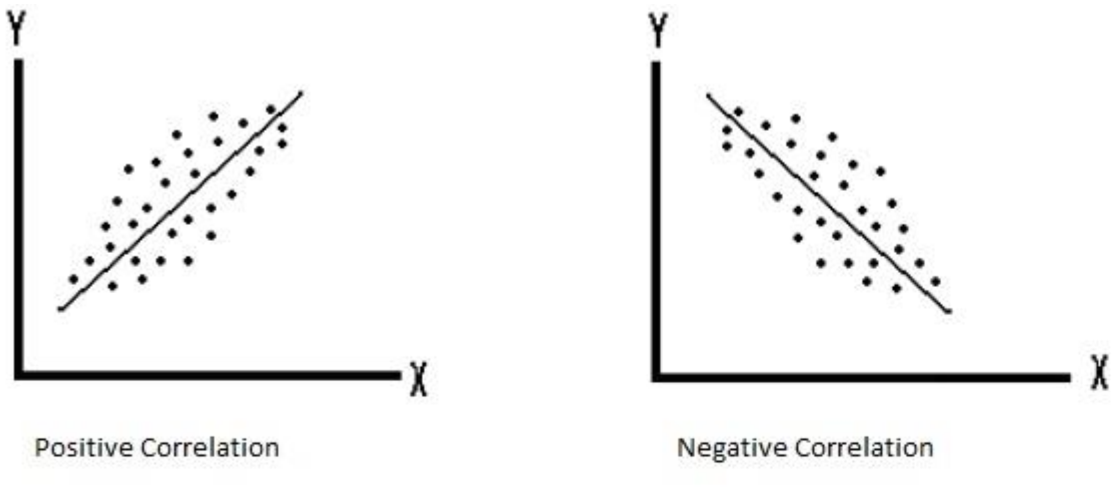


Figure 4-5 Positive and negative correlation between dependent and independent variables

Multiple Regressions is another well-known technique that is a more sophisticated extension of correlation and investigates the ability of a set of independent variables on one continuous dependent measure (Pallant, 2010). Correlation coefficient is symbolised by “r” and the formula for calculation is given as following;

Equation 3- Correlation Coefficient Formula

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\left(\left(\sqrt{\sum(X-\bar{X})^2}\right)\left(\sqrt{\sum(Y-\bar{Y})^2}\right)\right)}$$ (Fink, 2003, p56)

$$-1 < r < +1$$

There is an important warning that has been noticed by Fink (2003) in using correlation test. The correlation is suitable to indicate the relationship between independent and dependent variables, however, **strong correlation relationship between variables cannot claim refer to cause and effect**. For instance this research would claim that there is strong relationship between using 5D modelling and information accuracy in structural engineering whereas it cannot be claimed that in structural engineering organisation the information is accurate because those organisation use 5D modelling.

Measuring correlation between ordinal data the Spearman's rank correlation has been suggested (Keller, 2012). Spearman's rank correlation coefficient is one of the methods for evaluating hypothesis. The degree of relationship between two ordinal variables can be presented by this descriptive statistical method. After running either pearson or sperman test through SPSS, a table of results will be provided. This result presents correlation coefficient, significant level and number of cases. Pallant (2010) expressed that firstly, number of cases should be check to find out if there are missing data or not. The second factor which should be considered is the direction of relationship between variables. The interpretation of correlation direction depends on the way that questionnaire is designed and variables scored. This interpretation can be also conducted by considering scatterplot. When a relationship between variables is positive it means high score on one variable is correlated with high score on the other variable. On the other hand, when a relationship is negative it means high score on one variable is correlated with low score on other one. The third factor that could be determined from correlation in SPSS is the strength of the relationship. As it has been presented in correlation coefficient formula, "r" indicates strength of the relationship and ranged between -1 and +1. Different authors recommended different methods for interpreting of strength. Pallant (2010, p. 134) mentioned the following method according to Cohen (1988) as following;

Low strength $r = 0.1$ to 0.29

Medium strength $r = 0.3$ to 0.49

High strength $r = 0.5$ to 1.0

4.7.4.2 Multiple Regression

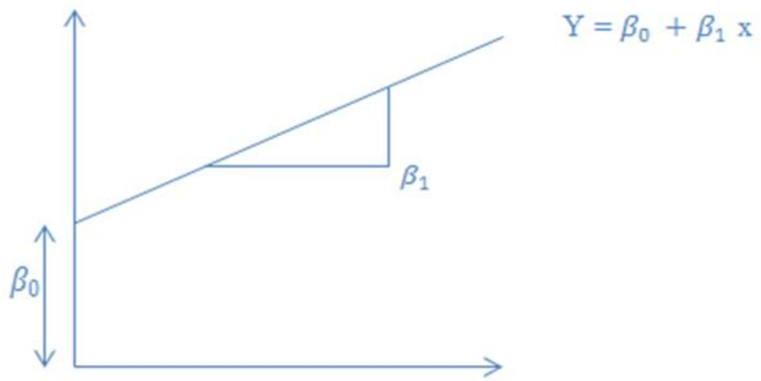
The major difference between correlation and regression is explained by Fink (2003, p61). The relationship between variables are examined by correlation test however, the value of mathematical model which impact on relationship between dependent and independent variables can be estimated by regression test. Multiple regressions consists family of techniques to examine relationship between one continuous dependent variable and number of independent variables (Pallant, 2010, p148). Multiple regression is often applied to determine how well a set of variables are able to predict a particular outcome and which variable is the best predictor.

There are several various multiple regression tests and researcher can choose one of those based on the nature of research question. The three major categories of multiple regressions are standard, hierarchical and stepwise (Tabachnick and Fidell, 2007). In standard regression all the independent variables are moved into equation concurrently. In standard regression all independent variables can be compared from each other in terms of their predictive power. In hierarchical regression each independents variables are entered into blocks and each will be evaluated to explore how much it is adding to prediction while other variables have been controlled. In stepwise multi regression a list of independent variables will be provided and then this test decides on which variables should be used in equation (Pallant, 2010).

In the simple regression there is one predictor in equation. The regression equation can be presented graphically as illustrated in figure 4-4. In figure 4-4 the simple regression equation is shown as regression line. The regression line crosses in Y for each unit change in X. The slop of regression line presents the quantity of changes in Y for each unit change in X (Fink, 2003). The positive slope of regression line shows while X rises, The Y will rise despite, negative slope shows X rises as Y reduced (See Figure 4-6).

Simple regression equation $Y = \beta_0 + \beta_1 x + \varepsilon$ (Badiru and Omitaomu, 2011)

Figure 4-6 Graphic interpretation of regression line (Fink, 2003)



Equation 4- Multiple Regression Equation

$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_k x_k$

Where; Y = predicted value on the outcome variable

β_0 = predicted value on Y when all x=0

x_k = dependent variable

β_k = unstandardized regression coefficient

K = number of independent variables

4.7.4.3 Factor analysis

Factor analysis is not suitable for testing hypothesis. Factor analysis is a technique to summarise variable to smaller group. Factor analysis is contained in SPSS to reduce data. The smallest number of factors can be determined by factor analysis. Those factors can be best representative of the interrelationships within a set of variables. It is assumed in factor analysis that relationships between variables are linear and this technique is relied on correlation analysis.

Factor analysis provide an opportunity for the researcher to test ideas regarding to variables, which are difficult to measure directly (Taylor, 2010). In other words, factor analysis can support confidence of a research that all variables are the same underlying factor or not. Researcher can obtain several outcomes from running factor analysis test through SPSS. One of the most important result is “eigenvalue” (Pallant, 2010). The factors with an eigenvalue of 1.0 or more will be considered in factor analysis exploration process.

Where dependent variables are defined as X1, X2,… Xn, the common factors are F1, F2,…,Fn (independent variables) and unique factors are U1,U2,…,Un. Therefore the regression function can be defined as following;

Equation 5- Regression Function Formula

$x_1 = a_{11} F_1 + a_{12} F_2 + a_{13} F_3 + \ldots + a_{1m} F_m + a_1 U_1$

$x_2 = a_{21} F_1 + a_{22} F_2 + a_{23} F_3 + \ldots + a_{2m} F_m + a_2 U_2$

…

$x_n = a_{n1} F_1 + a_{n2} F_2 + a_{n3} F_3 + \ldots + a_{nm} F_m + a_n U_n$ (Taylor, 2010)

a_{nm} is coefficient. For instance, the coefficient a_{11} shows the effect on variable x_1 . To achieve a score on each factor for each variable the equation can be formed as following;

Equation 6- Factor Analysis Formula

$F_1 = b_{11} x_1 + b_{12} x_2 + b_{13} x_3 + \ldots + b_{1n} x_n$

$F_2 = b_{21} x_1 + b_{22} x_2 + b_{23} x_3 + \ldots + b_{2n} x_n$

…

$F_m = b_{m1} x_1 + b_{m2} x_2 + b_{m3} x_3 + \ldots + b_{mn} x_n$ (Taylor, 2010)

The main aim of factor analysis is to describe correlation within observed variable with regard to small relative factors. The correlation between variable x_1 and x_2 is formulated by summing up coefficients for two variables across all factors. According to table 4-5, the correlation between variable x_1 and factor F_1 is a_{11} . And the number at the end of each factor column is the sum of squared loading for that factor.

Table 4-4 Correlation table in SPSS

Variable	**Correlation**	
	Factor1(F_1)	Factor n(F_n)
$\boldsymbol{x_1}$	a_{11}	a_{1n}
$\boldsymbol{x_2}$	a_{21}	a_{2n}
$\boldsymbol{x_n}$	a_{n1}	a_{nn}

Pallant (2010) explained all steps that a researcher needs to consider after obtaining output from SPSS for data interpretation. The first step is **to verify that collected data is appropriate for factor analysis**. It is recommended to consider correlation matrix table and if there are not many correlation coefficient more than 0.3 then the researcher should reconsider using factor analysis. In addition, it is recommended to consider Kaiser-Mayer (More than 0.6) and Bartlett's test of Sphericity (should be 0.5 or smaller). The second step is **determining number of factors to extract**. It is suggested in factors which have an eigenvalue of 1 or more. In this step, the Total Variance Explained table will be considered. The third step in interpretation data via factor analysis is **interpreting the plot**. The shape of this plot will be considering whether, its elbow or change in plot. The factors above the change in plot will be extracted. The Component Matrix will be considered in fourth step. SPSS will retain all factors which are likely to be more appropriate. The last step is to considering on the Pattern Matrix. This matrix shows which factors are being loaded by variables.

4.7.4.4 Analysis of Variance (ANOVA)

Analysis of variance is close to regression test. This statistical test is appropriate to examine and model the relationship between a dependent variable and one or more independent variable (Muller and Fetterman, 2003). The analysis of regression and variance differ in some aspects. Despite regression, variables in ANOVA are qualitative (Categorical) and there is no assumption established that refers to coefficient for variables.

The most of the ANOVA's interest is centralised on comparison of average of more than two populations. In studying ANOVA there are two important terms which are factor and level. Factor is characteristic which is under studying and level is a value of a factor. There are two types of analysis of variance. The first type is one-way analysis of variance. It helps the research to find whether groups differ, however, it would not find where the significant difference is. The second type is two-way analysis of variance. This test measure the impact of two independent variables on one dependent variable (Pallant, 2010). Some of the well-known parametric statistical techniques have been studied up to now. The next section discussed the justifications for adopting descriptive statistical analysis, factor analysis and multiple regressions as statistical techniques to analyse quantitative data in this research.

4.7.4.5 Statistical test adoption justification

The First part of questionnaire survey in this research measured on nominal scale data. These data did not consider numerical values however, this research intends to describe frequently that they occurred. For example, participants have been asked to specify their current job role in their organisation. Analysing these sort of data there are suggested some descriptive statistics including proportion, percentage and ratio (Gatignon, 2010). Proportion describes numbers of responses with specific characteristic divided by the total number of responses. The percentage is a kind of proportion from which can be described in hundredths. The ratio describes the relationships between two different parts. The ratio is the number of responses in a given group with a specific characteristic divided by the number of responses with another characteristic.

The second part of the questionnaire examined a summary of the information management challenges of the participants' responses given in scores. This part of the questionnaire seeks to explore most critical challenges in structural engineering information management domain. Those responses have been analysed through Weighted Score (WS). WS represents ranking of each challenge in structural information management against the total number of participants. This part of the questionnaire also explored respondent's weighted score of utilisation of BIM technological tools, workflow standards and human resources strategies in their organisation.

The third part of this questionnaire considered to discover that whether a relationship exist between using BIM technological, workflows, and human readiness and information quality in structural engineering organisations. This research examined from literature review and qualitative case study interviews that information quality in structural engineering industry can be measure by interoperability, accessibility, accuracy and security. Therefore in this questionnaire survey there are four dependent variables involved in this analysis. This questionnaire survey is designed to test the effect of information quality by using BIM dimensions. Therefore, this research will examined the BIM criteria which impact on the information quality satisfaction. The criteria for adopting each BIM technological, workflows and human resources readiness have been examined from the literature review and qualitative case study. The questionnaire requested participants to rank BIM criteria outcomes (independent variables) within the context of technological, workflows and human resources perspective in their organisation, as well as information quality dimensions (dependent variables). Hence, this research seeks to measure the relationships between independent variables and four dependent variables (accessibility, accuracy, interoperability and security). In another words this research will seek to find a statistical technique to measure how independent variables can predict dependent variables separately.

This research should take into consideration for parametric statistical alternative. Non-parametric techniques do not make any assumption that refers to population distribution. Parametric techniques are perfect while data are being measured on normal and ordinal scales (Pallant, 2010, p 213). Factor analysis will be an appropriate option in this research to explain a set of fewer factors plus weightings. This research need to verify that the collected data is appropriate for factor analysis before conducting the analysis. The main requirement of factor analysis is normal distributed data. Therefore this research checked the normality of data before conducting the analysis (See Section 6-5-1). This research expects that many of the identified independent variables can be correlated to dependent variables. This research expects that information quality in structural engineering industry explains the identified variability of the measurement. Factor analysis can be applied to test this idea. There would be another idea that some identified variables are not correlated with information quality which has some independence from information quality. Therefore factor analysis could support the confidence of this research that all or most of variables which this research measured are the same underlying factor or not. Factor analysis also allows this research to diminish variables to a smaller and more manageable set of factors. Factor analysis contributes to this research to test which independent variables and dependent variables categorised under the same component or factor and this technique aids this research to test the must correlated relationships between variables (See Section 6-4 for more details).

This research also adopted multiple regressions while the components (factors) presented through factor analysis. The multiple regression enables this research more explorations within a set of variables. The multiple regression also increases research reliability in predicting values for the dependent variables. The multiple regression technique has been conducted to evaluate relationships between independent and dependent variables which are categorised into components through factor analysis. The independent and dependent variables which are categorised into the same component are entered into regression model in the same time. It means that this research consider regression model for each component (See section 6-5 for more details). The Statistical Package for Social Science (SPSS 20.) is used in both Factor analysis and multiple regression tests. Next section justified reliability and validity of the research data analysis and findings.

4.7.5 Reliability and Validity

validity refers to degree of accuracy of the research results and reliability refers to accessibility of the results (Saunders et al., 2012). This research adopted several approaches to achieve validity and reliability in its results. As it has discussed in previous section (Section 4.3.1) this research adopted mixed method approach, and mixed method contributed to this research to enrich the understanding of the phenomena and increase the level of validity trough qualitative method or exploring and testing bigger sample of experts through quantitative method and improve the reliability of the results. In the following paragraphs the process of validity and reliability in this research has been discussed in more details.

During qualitative case study in the context of qualitative data reliability, this research sent back interview transcripts to interviewees to confirm whether the transcripts present their opinions. In terms of validity context, this research triangulated data from two different cases to enhance validity of evidences and adopting it to create a coherent justification for themes. In the context of questionnaire data collection, a measure can be reliable while the value of measurement repeated on the same phenomena (Rubin and Babbie, 2011). There are several techniques to test the reliability of the data measurement. The first tests are classified into test-retest method. In test-retest method same objectives will be measured several times and while the value of objectives repeated in each attempt, it can be claimed that data is reliable.

The other type of measuring reliability is internal accessibility. These methods allocate the questions into groups which measure the same concept. Cronbach's Alpha is the most common used internal accessibility measure of reliability (Streiner, 2003). Correlation coefficient will be calculating in Cronbach's alpha method, when correlation coefficient is close to 1 it means reliability of data is high. The ideal correlation coefficient for reliable scale is 0.7 (DeVellis, 2013) however cronbach's alpha correlation coefficient is very sensitive in scales which contents few items. Palant (2010, p97) argued that in that case it is common to find 0.5 (see section 6.5.3 for reliability checking of questionnaire.)

In addition to confirming reliability and validity in qualitative and quantitative result, the conceptual framework for implementing in structural engineering discipline as a guide will be final result of this research. Hence, reliability and validity of conceptual framework should be also taken into consideration. The conceptual framework has been validated through interview with six experts. Three of them had structural engineering background and three others are BIM academic researchers with background of implementing BIM in AEC industry. Those experts comments will be consider in terms of clarity for industry, applicability in industry, comprehensiveness and novelty.

4.8 Ethical Consideration

In this research, participants were not to be subjected to increase risks of physical or psychological harm through taking part in this research. Interviews were carried out in locations and telephone conversation in which the respondent is comfortable. And questionnaires link were sent to respondents thought email. The researcher invited both interviewees and questionnaire respondents by email and confirms the acceptance by email. It has been described briefly to assure the participants that their name and their organisations name will not be published and this research utilised codes instead their names. Participants who were being interview or filling questionnaire are told in an email that they can withdraw prior to the interview any time before, during and after the interview. The researcher's contact number and email are mentioned in all emails, in the case of any questions. The ethical approval has been issued by University of Salford to the researcher which allow researcher to collect data from structural engineering organisation through interview and survey.

4.9 Chapter Summary

This research adopted interpretivist paradigms using qualitative and quantitative methods to achieve specified aim and objectives. This research triangulated qualitative and quantitative methods to provide conduct an in-depth understanding of the phenomena. This research needs multiple sources of evidence for data collection. Therefore, it was supported by multiple case studies among UK private structural engineering disciplines who have experience in implementing BIM. Interview and questionnaire techniques were adopted for main data collection due to collecting both in details data from actors' perceptions by interview and data from larger sample via questionnaire. The qualitative data from interview was analysed using Nvivo 10 software and statistical data analysis from questionnaire has been analysed using SPSS 20 software packages.

In first stage of data collection, two structural engineering departments in two large multidisciplinary design and construction organisation have been studied. The case studies involved interview with structural engineers, design managers and BIM manager practitioners promoting BIM implementation practices. In the second stage, a link to a Survey Monkey website questionnaire was sent to 300 structural engineers, BIM managers, design managers and researchers who have experience in BIM implementation in structural engineering discipline. Respondents' Linked In profile page has been considered to select relevant participants in terms of job role and experience in using BIM in structural engineering domain. Two reminder emails have been sent to all respondents and finally 125 respondents were replied back to the researcher within two month. The final phase involved the analysis of both qualitative and quantitative data and the development of a conceptual framework. The next chapter presents the qualitative data analysis of interview and shows the results to achieve research questions.

CHAPTER 5. QUALITATIVE DATA COLLECTION AND ANALYSIS

It has already been pointed out in chapter 4 that two cases were investigated by interviewing relevant participants. These participants responded to questions with a reflection of their on-going projects. Qualitative data analysis has been carried out in this chapter with an aim to discuss and comprehend the opinions of the interviewee with respect to the challenges in information management in their current project and the solutions that may help enhance the information quality in each case. Thematic coding scheme has been applied before starting the qualitative analysis of this research. There are two categories of this coding system: context and keywords. The context and keywords that have been finalised from both cases were used to further refine the conceptual framework.

5.1 Case 1- Qualitative Data Analysis

The data collected and recorded was sorted into themes. Themes provided the storage areas in NVivo for accessing coded text (Bazeley, 2007). The key words have been categorised into relevant themes (nodes) as shown in Figure 5-1.

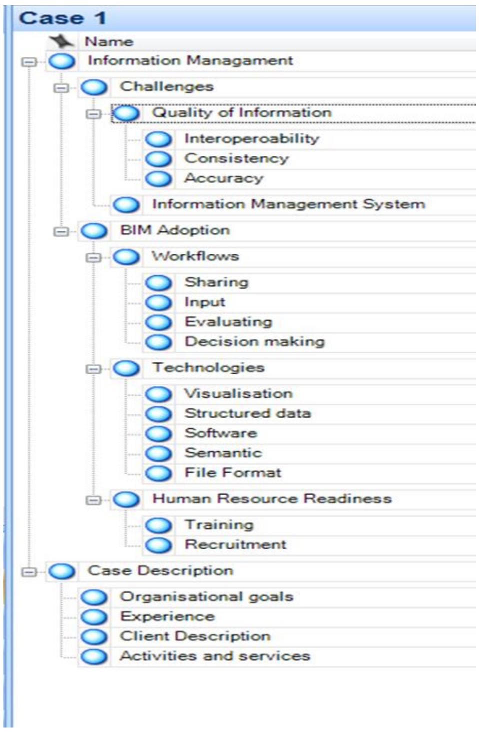


Figure 5-1 Themes of Case1 from NVivo

5.1.1 Case1 Description

Case 1 has been sourced from a project in a structural engineering department that forms a part of the design team of Company A (See section 4.4.2). A multi-disciplinary construction and civil engineering organisation, company A is a leading integrator of complex, sophisticated and innovative buildings and design projects. With an annual turnover of 10 billion pounds, and employing 15,000 workers in the UK, Company A has a significant global presence with two times as many employees worldwide. The case investigated was the structural design of a hospital that was being delivered by company A which had been entrusted with the design, funding and construction of the hospital and also for providing facilities management. Most of the participants highlighted that integrity; team work and respect are the overall goals of their organisation. The participants believe that knowledge sharing in their department is the key element to achieve stakeholder satisfaction. For example participant SSE1 expressed as follows;

> "…*Stakeholder satisfaction is the key and everything supports it. There is a big push at this moment, and it is most relevant to this discussion on knowledge share and contribution though hardest in the power group…*"

As part of organisational success strategy, the senior managers in Case 1 developed outlines emphasising on organisational values of integrity, respect and team work. It was agreed by the majority of the respondents that these outlines play a very significant role in the contribution towards the built environment in the UK. The most important observation in the organisational description in Case 1 shows that, one of the biggest challenges is the lack of communication and cooperation between different disciplines. For example participant SSE4 expressed as follows;

> "…*It is actually been the case that for any reason different business disciplines never speak to each other…*"

Overall, the responses from the participants emphasised that their organisational strategies may improve reputation, integrity and team work, but, in the current hospital project, the client had raised several complaints related to mixed messages and poor quality of information. It is evident from Case 1 that although the goals for all structural engineers are leading the sector, profitability, increased market share, and leading reputation in the industry, most of the participants believe that there is a lack of an information management strategy that would lead to success. For instance Participant DM1 stated that:

> "…*We have got excellence, sector leading, and profitability through operational excellence. We have got integrity, increase market share through becoming the partner of choice; we have got respect, industrial leading reputation by building the trust of brand and finally teamwork. Potentially there is a lot of repetition, however, potentially for some customers, have same issues, mixed messages going to people…*"

Organisation A offers construction, transportation and power. Case 1 is a conceptual and detail of structural design of a Hospital project in organisation A. 78% of the funds for the Case 1 project were provided by the government, and the local authority represented the main client for the project. Most of the project communication in Case 1 was between the Local Authorities, architectural department and contractors. The architectural department designed the scheme which in turn was confirmed by the client, in this case the government represented by the local authority. The general design, services, design management service, and innovation and sustainability development for Case 1 was provided by Organisation A. Case 1 was the provision of feasibility study documents, conceptual design documents and detailed design documents to the client, local authority and contractors. Participant SSE2 expressed as follows;

> "…*We get involved in feasibility projects through support in clients enable to driven that face of works through funding applications, Information and detail design. The other part of the project life cycle will be conducted in other departments of our organisation such as construction, operation maintenance and eventually dig emission in some aspects of project…*"

5.1.2 Information Management Challenges in Case 1

Majority of the participant held the view that in a project, the structural engineering industry relies heavily on information input by various disciplines. The project based nature of the structural information industry was stressed by the participants who emphasised that an effective information management system could enhance the level of information quality and lead to a better quality of project delivery. Overall, most of the participants felt that the nature of the structural information management environment is heterogeneous and complex as the data is collected and forwarded to various disciplines and applications. This information has been complied by various occupations, professions and applications in the Case 1 project.

Most of the respondents were of the opinion that a lot of time was spent in opening the information by various applications in Case 1 as **different format of information** were used. It was pointed out by around two-thirds of participants that they did not face any issues in terms of mapping of information between the structural department and other disciplines while working on the internal information system. However, different information formats lead to miscommunication with the external collaborators. In Case 1, various participants faced problems in reading the information that had been created by different organisations. Structural engineers in Case 1 had to revert back to the original generators of the files that they could not link to the internal servers. Participant SSE3 and SSE2 expressed as follows;

> "*…I think the challenges are different format of information and more often it's the timing of information…*"

> "*…One big thing which is fairly you have DWG files, X –ref other files you don't get. So you can't read the information. When you ask the question from the originators they don't know either because of x-ref is been done by their server to files all over the place which is fine it's set up Historically by number of people you can trace back to originate files. When they pick up DWG externally it's useless. You can't quickly resolve the problem because it's linking internally to the server. It's happen to me two weeks ago. Its common problem, it's something we are hopefully trying to solve by using shared work base so we say to consultants, look I want you to keep everything in your own server…*"

Most of the interviewees felt that while designing the hospital project, the requirements of the client kept changing from time to time. Thus an efficient information capturing system was a critical requirement as it would help to manage capture, storage and retrieval of explicit related information. Participant SSE4 argued as follows;

> "*…Things can change very quickly and managing the changes is very tricky in our job…*"

As pointed out by majority of the Case 1 respondents, one of the significant challenges is the **availability of information at the requested time**. A situation was described where one of the designers who works on drainage was based in Glasgow, Scotland and the structural engineering team was based in Manchester, UK. Although they are working on a shared platform, each designer received information that was beyond the shared platform. The major information management challenge in Case 1 was to update the shared platform with current information. In other words, one of the main challenges identified in this research is the interaction of internal and external information. In Case 1, the critical challenge was to synchronise the internal system with the external system. Participant SSE3 expressed as follows;

> *"…The challenge is what the latest information is and who uses in it. Somebody working on design and somebody working on drainage and office in Glasgow and the progressing is shared in parallel and that's the problem to manage that information. Recently we are setting extranet system up to default the prepare job that's for few months we have been doing that. But our company procedure is to use our company intranet system…"*

In addition interviewees in case 1 indicated that they were required to adopt or provide a **standard practice** to show the users what to put in the internal system, what it can be used for and what status it is and some designers will become more familiar. Participant SSE1 expressed as follows;

> *"…with questioning in status or something. I put contractors as well and from better experience as soon as something appear in the drawing, builders take that as fact and going to use it an angel when in reality it might not be appropriate to do. People thinks when something is printed its reality and it's dangerous if everyone can access to that so it needs to be controlled properly..."*

Other challenges mentioned by Case 1 participants were related to **tacit knowledge repository**. Each construction project is unique and creates a significant amount of knowledge during execution, however, most of the knowledge remains in the minds of the designers, or is not retrieved in an efficient manner to be available for future projects. As already mentioned Organisation A is a large sized organisation and has a well-developed corporate intranet platform for sharing information. However, their system mainly shares explicit knowledge such as standard forms, drawings, design reports, cost of materials and so on and there is no scope for sharing of tacit knowledge. It was suggested by some of the participants to incorporate a **blog or wiki system in their intranet corporate platform** to enable design members from various different disciplines to store and share their routine knowledge about the project, under the headings of time, discipline and project description.

At this time the participants also added that the information inputs created should be approved by the organisational administration and also should be controlled by an efficient **administration domain**. In addition in Case 1 structural design participants prefer to keep whatever they are doing separate from the shared platform **due to information security**. For instance Participant DM1 argued as follows;

> *"...People thinks when something is printed its reality and it's dangerous if everyone can access to that so it needs to be controlled properly. You get disk with password protection, if you don't know the password is. All the things I would say are simple Admin issues. They don't like doing that 1- because of data security and 2- they want keep whatever they are doing behind and while happy release it, it is simple..."*

In Case 1 the target of the design manager is to make the project efficiently integrated as possible. The project is controlled by the design manager to ensure that all the milestones such as cost, time, quality, safety and sustainability that have been specified by the client are met. In Case 1 the design manager stressed that the most critical challenge is **tracking every design participant's work**, and to determine the most efficient strategy to achieve related information resources. In other words controlling the quality of information is the most significant challenge for the design manager in Case 1. For example participant BM1 expressed as follows;

> *"..So the big challenge I have got is to trying to identify what everybody does, where is the gap, which is the best way to get information resources and how could I make it as an efficient autonomist project as possible, cause if we don't want to do, I am sure that design manager is at the end of it, is be the guidance on site trying to build the job safely, build to high quality, make sure that we made money and by the way you have got filling this 8 hours Shift and provide us with this information and this information goes into a black hole and you never get anything back to know is it good information or bad information…"*

The design manager and the sustainability manager expressed that the area of greatest concern was the accessibility of information available at one place. Thus, **accessibility of information** was the biggest challenge identified by design managers in Case 1. Information has been ordered from top management department and from client to design department and it is important to achieve and deliver it in the requested time. If everybody knows where the requested information is and how to obtain it, it is consistency of approach. This means that if the design team is miles away from the management who cannot visit them regularly, a day to day discipline and consistency exists that provides comparable information with other engineering data. The problem pointed out by the design team is that there are doubts that the information is not consistent with other legacy operator company so it's a case of "needs to training education process". The big problem then is **communication**. For instance participant DM1 expressed as follows;

> *"...So my biggest challenge is not necessary about whether they to start how we capture it my biggest challenge is accessibility, accessibility of data because, what would happen is; we are got ordered it on annually from dnv but we also get from KPMG against sustainability performance. And what I am doing is building a system sustainable when KPMG come to us on summer I have got one system that all information in one place consistence. I have 500 excel sheet and I am not able to put it all together. Then its human decision at the end of it with IT support..."*

Several assumptions are made by structural engineers to simplify their calculation models. In Case 1, these assumptions were made with the aim of making the model smaller and hence quicker to run. This also makes the model more suitable for a particular analysis of solutions. For instance, in Case 1 structural engineers Ignored holes in floors and walls and the correct walls and floors were assumed as straight faces. Most of the participants in Case 1 were of the opinion that the majority of these assumptions are valid in terms of the individual model but they were unsure about its validity in terms of the overall building structure information. The participants stated that complex architectural models will produce complex structural models with geometry including non-rectangular opening and curved slabs, etc. In Case 1, these issues affected the **accuracy of information**. The participants in case 1 argued that the accuracy of information in terms of states and stages in the design project is very important and especially in their shared platform they cannot exert proper control. In this regard, participant SSE2 pointed out that:

"...If the input into share shared space isn't correct in terms of states and stage in the process then it's a very dangerous thing to do, so the exchanging the information in that context is the better because it can be question questioned and people can ask and understand what's going on. In the shared platform everyone can access it and use it and it would not be properly controlled..."

As it has been discussed earlier (See Section 4.4.2), this research adopted content analysis for analysing qualitative data which is collected from case study. Therefore, for summarising very critical challenges in information management in Case 1, The number of interviewees who expressed a challenge and percentage of transcribed text related to the issue are considered. A very high rate challenge was indicated where four and more than four interviewees with more than 2% of transcribed text related to a particular point. Three interviewees with between 1% to 2% transcribed texts related to particular issues indicates high rate challenge and less than this indicates medium rate challenge. As shown in Table 5-1; information accuracy, information accessibility, information interoperability, information security, lack of communication and inefficient tacit knowledge repository are the very high rated challenges in Case 1.

Table 5-1 Information Management Challenges in Case1

Information Management challenges in case 1	Text percentage in transcription	Interviewees References	Rate
*interoperability	2.5 %	6/6	Very High
*Information accessibility	3.1%	4/6	Very High
Lack of standard practice	1.3%	3/6	High
*Inefficient Tacit knowledge repository	3.0%	5/6	Very High
*Lack of communication	2.5%	4/6	Very High
*Information Security	2.5%	4/6	Very High

Tracking information	1.8%	3/6	High
Information timeline	1.4%	2/6	Medium
Administration domain specification	1.3%	1/6	Medium
*Information Accuracy	2.5%	5/6	Very High

Majority of participants stressed that they had an efficient information management system internally, which was simplistic and comprised of either paper copy files or information on shared networks or on internet. Challenges are faced when external parts are involved. Most of the intranet system was run by organisational employees, but of late, Local Authority has prodded the structural engineers to utilise externally accessible extranet systems with proven success and standards. Problems arise as it is yet to be incorporated in the existing company procedures. For instance participant SSE4 expressed as follows;

> *"...At the moment whilst the local administration is forcing everyone to use the extranet system, and the company is interested in using internet system then procedures are going to be duplicated and duplication in information management is dangerous. Because people don't want to work in both places, so that's problem at this moment and the further problem with the external sites is some of the external people who want to access them can't because the internal IT system does not allow them to access external websites for example. Particularly local authorities control who can access the IT system. So it is a process problem that is being addressed and another problem is change..."*

5.1.3 BIM Adoption in Case 1

It was claimed by the BIM manager and other designers in Case 1 that BIM was adopted to optimise their information management system; however, they were unable to clarify the level of BIM incorporated by their organisation. With reference to the investigation in the literature review of this research, the adoption of BIM involves applying related technologies, workflows and human resource recruitment and training. The following sections of this research will analyse the responses that have been collected via interviewing participants in Case 1 related to BIM adoption in their organisation.

5.1.3.1 BIM Work flows in Case 1

It was found in this research that none of the available BIM workflows in the UK, such as PAS1192 had been adopted by Case 1, which had however, established its own information management map. This information management map demonstrated procedures for **creating information, communication and decision making**. Established by design managers, the information management map aspired to reduce clashes, reduce CO_2, reduce wastage and improve health and safety. The information management map in Case1 (IMMC1) starts with collecting the drawing from the architect, inputs structural engineering geometry to the model and develops reports for client and local authorities, evaluates the model and finishes with the final decision making.

The IMMC1 is based on the UK government policy which has been published in the government construction strategy in May 2011 to pursue construction sectors to apply BIM level2. In Case1 structural engineering and other design department work in remote branch offices, using the cloud information management system. The BIM manager established information management map to ensure all **design documentations is maintained in the latest version** and **stored in a single location** and is **ready for retrieve in later project**. Regarding to this issue, participant BM1 argued as follows;

> *"…open to recently from what I understand it's similar in terms of base of information for the use in site and the information that building needs to achieve when its complete and another set of information on material properties and component properties used to put together in…"*

Structural information producing in the Case1

Information is contained in the documents, and in Organisation A, these documents are created with special intents and purposes. In IMMC1, the documents are categorised as general and technical. General documents comprise mainly of communication documents such as contents of emails, letters and minutes of meetings. Technical documents consist of drawings, descriptions of properties, descriptions of activities and bills of quantities. Final technical documents include approved documents for Organisation A that would have been issued for construction purposes. In the IMMC1 system, each technical document is recognised by its own revision that has been issued with two main attributes which are the date and the revision references.

In Case 1, a document control system is in place to manage the technical documents. This enables the designers to upload their information which other people can access and download. Majority of the participants were of the opinion that this document control system ensured efficient information flow and the document management was efficient enough to achieve successful management of the design and construction process. In Organisation A, this document control system had been designed and developed by a group of the construction technology service department. Participant DM1 pointed out that:

> "*…We generally use our document control system as some online platform on which some people can upload their information which other people can download and use and its control, and management system...*"

Structural Engineering Information Sharing in the Case 1

The initial building information model in Case 1 would be developed by the architect and the drawing document would be uploaded on the document control system. Structural engineers would then download the initial model and alter the sizes of certain structural members based upon the strength criteria. The building information model would then be uploaded on the document control system for updating the architectural building model. Thereafter, architectural, structural and building services information will be added to the building information model for construction purposes. Therefore all the design disciplines produce only one model rather than several models. Regarding this issue, participant BM1 expressed as follows;

> *"…Our projects have extranet site which has all the information relevant to project are on it and as long as client is willing and enable because IT system restriction to access to site as long as everybody involved to the project and brass it and use it, people start navigate by email because thing are missing on it and people don't trust it..."*

In Case 1, the design manger is in charge of matching the final technical documents with the client's requirements as issued in the contract. The design manager holds the opinion that the final decision in structural elements, sustainability strategies and construction activities will be conducted based on the requirements specified by the client and the local authority. Interviewee DM1 stressed that:

> "…*Its share based absolutely we have formal meetings and discussion. I mean at the end of the day the requirement should be the contract, reality is contract based line and discussion involved in design decision making. So yeah we are focusing on process on mechanic rather than on discussion on solving the problem*..."

Interviewees SSE1 and BM1 stressed that with a view to sustainability, Organisation A stores all technical documents related to previous projects on the intranet system. These include the technical sustainability documents that have been collected from contractors and are based upon the information collected during the in-site construction phase, for instance the amount of carbon generated in the previous projects. Sustainable outputs in relation to the designs are analysed by structural engineers, making it simpler to make more sustainable decisions in the current projects. Basically, all the structural information is stored in one portal and is reported to the upper management on an annual basis. In this context, interviewee SSE1 stated that:

> "…*From the sustainability point of view our outputs are very much in the term ENABALON that I mentioned. It is a Douche system where you put all the information and get the question and architect the built. It speeds up our annual reports, how much carbon we produce, basically all the information goes to one portal and the biggest output is the annual report which you need to send to the stock exchange every year...*"

Based on the analysis of Case1 it has been found that there are two differences between structured and unstructured information management. First of all, **structured data can be updated regularly**, however, unstructured data most of the time cannot be changed after developing. For instance when an email is written and sent or a contract signed, changes will not be possible.

Structural Information Evaluation in the Case1

Two different viewpoints about the evaluation process in Case 1 were observed in this research. The first group of interviewees including SE2 and SE3, stressed that the evaluation phase in Case 1 does not take place on a shared platform. Structural engineers, design manager and client prefer to sit around the table and discuss about the model and reports. Their comments refer to the drawings and reports collected from the client and other disciplines during the meeting. However, in Case 1 some comments are contradictory to each other and the design manager cannot resolve it without understanding the background of the interviewees who have made the particular feedback. Most of the participants argued that, the evaluation process of the structural models and reports by **remote electronic comments** take a long time. For instance interviewee SE2 expressed as follows;

> *"...Simply form really. It could be in shared platform. But most of the time sits down around the table and discussion. Some of them are obvious, you go to key items would be discussed. Most of the comments take in multidisciplinary environment you get 3 or 4 different comments in the same thing that contradict so you can't address those comments with new solution because it's impossible so some compromised and some areas necessary may effect. Design number 6 has changed the design which is another reason we talked about earlier and through description, probably face to face. Then we have 5 or 6 different comment in online environment which are contradict to each other and you can't resolve it without understand the background to why people and who is going to compromise to make solution. If you try to do that by remote electronic comments it takes months…"*

The second group of interviewees including SE1, DM1, SE4 and BM1 argued that in Case 1 there is a system called swift research. The purpose of this system is to access the data base that stores all information related to previous projects. The structural engineers, architects, client and design manager use these information to evaluate the information currently produced by them and compare with the results of the previous projects. Regarding this discussion, SE4 interviewee expressed as follows;

> *"In terms of feedback, we can touch with GPS we do in this office performance measurement. We sitting in the long side we use an external "Swift Research". And Swift got the data base of all customers and the project that we done recently. And*

ask questions for example how it performs in terms of safety and how it performing in particular questions in design. And then put together into a document. I was involved in the project about sustainability but we twit the word sustainability in the questions to be simple for the customers and got their views by swift research."

On the assessment of the opinions of both groups, it can be inferred that the information evaluation process takes place during the meetings. Of the two groups, only the second group participated in the Swift Research Project that was designed for more efficient evaluation of information. From these observations it can be understood that **in the Case 1 project there is no defined information evaluation process**. In Case1 it is the design manager who is the last person to control the drawings and reports from all compiled feedback from different disciplines. In this context, the interviewee SE1 pointed out that:

"...So it sounds like an informal process, but it is so because the control is by our design manager who ensures that the options are available in the correct format, the decision has been made in the right way, and if in the process it is found that a better engineering solution is available but the client has actually not asked for it, or if any unexpected cross problem crops up..."

The following sections will be devoted to the investigation of the technological BIM tools employed in Case1.

5.1.3.2 BIM Technologies tools in Case1

As discussed in the previous section, IMMMC1 is the information process map that has been is developed and applied in Case1. This map directs the design team to enhance information management through BIM level 2 which includes managing 3D environment with the attached data, but has been created in separate discipline models. The technologies which moderate the process of information management in Case 1 are classified into visualisation, file format standards and data structure, semantic and software.

BIM Information Visualisation Tier

As discussed in section 3.2.1, data visualisation means a computerised information system that provides an environment for users to create their own visual representation and also enables them to sort, filter, highlight, zoom and coordinate the visual representation.

Interviewees SSE2, SSE3, DM1 & BM1 argued that, the ability of data visualisation system can play a vital role in terms of time, profit, quality, regulatory and safety issues of structural engineering projects. The majority of interviewees in Case 1 stated that the appropriate virtual data environment should cover product models, work process and cost and value of capital investment in order to support business goals.

It was pointed out by interviewees BM1 and DM1 that in the Case 1 project the virtual design environment represents mostly physical and functional aspects of products. The physical aspect represents the geometry details of the building components and the functional aspect describes the purposes of the component such as to support loads. The majority of interviewees (SSE1, DM1, BM1 and SSE4) claimed that the critical defect in virtual environment system is inefficient representation of predicted product concepts and activities concepts. The predicted product concept refers to cost and schedule (required time to do a product and expected date to be installed) of each product and the activities concept describe the people who do the work with description of size and skills. Virtual environment in Case 1 needs to be developed by adding cost, schedule and worker's description to the product model. Therefore Case 1 as a structural engineering project desires to produce not only product model but also process model as both are highly interdependent.

Majority of interviewees in Case 1, including DM1, SSE3, SSE4 and BM1 claimed that in the design phase, computer visualisation techniques play a key role in the decision making process. It is in the conceptual stage of design that the computer visualisation techniques have a significant role as most of the crucial decisions are taken in a very short period of time. It can be understood from the interviewees that the visualisation of the output product which will be delivered to the contractors is also very important for the decision makers in Case 1. The critical factor in Case 1 in terms of visualisation is to produce product which can be visualised in a constructible and reliable format. This issue was stressed by interviewee SSE3 who stated:

> "…*At the moment we are carrying out trials of site automation in 5 projects, involving everyone from the site teams, including all contracts managers, subcontractors who have to detect any issue or problem that they may find. For example, if you are in a room and there are building project and lap connection is not right you can take a photo, highlight it and automatically get to right person. The idea is that, the first thing that construction manager does in the morning,*

just turn on his ipad and check on it and see the list of things that need to do that is already prioritised. There is trial going at the moment to get that point in very specific projects and it is going to be at the back of exercise to see if there is any variability to actually do that..."

Various computer visualisation applications for design, such as 2D and 3D modelling and simulation of construction schedules have been used in Case 1. The 3D technology in Case 1 allowed the structural engineers to view their model in a safe environment and also enabled them to test several factors without building the real structure. By using 3D simulation, the first factor tested by structural designers is **Performance prediction**. They can obtain valuable 3D insights and decrease the risk of failure by precisely predicting how their model would withstand and respond to extreme use. The second factor is **design optimization**. They control material usage and avoid over-engineering design by applying innovative simulation designs. And finally they can prevent costly mistakes by **simple model simulation** choices of components prior to the construction phase. Regarding to this issue interviewee SSE1 expressed as follows;

"…*Using intelligent design tools add value across the project lifecycle and by powerful visualisation tools you can walk through your idea successfully, creating more opportunity for new projects. We can simulate building performance and utilise great analysis tools to take informed sustainable design decisions*…"

BIM File Open Standard Management Tier

In Case 1, the internal stakeholders comprise of architects, structural engineers, M&E engineers and contractors, whereas suppliers and manufacturers are the external stakeholders. All these stakeholders need efficient methods for working which consists of roughly five thousand files in various formats such as CAD drawings, PDFs, Microsoft Office files and image files.

"…*We collaborate more and more when we use 3D models to collaborate and if we don't use 3D model then we will sit around the table talking about drawings, looking at details and using old fashion CAD drawings. But we are doing this less frequently and now we bring things together in Naviswork environment so we can check the clashes and etc*…"

In Case1, it was pointed out by the interviewees that the architectural data constitute the main input. The architectural drawings contain a lot of information that are rationalised by structural engineers in their first stage to produce engineering information. Initial architectural information in Case 1 includes drawn information, block plan and site plan. Drawn information describes the assembly of the building and initial sizing and position of beams, columns, slabs and walls in 3D. The block plan describes the location of the building, in relation to the city plan or other wider plans. The site plan identifies the position of the building works and access and general layout of the site. Structural analysis and design process take place after the initial architectural information has been submitted through the intranet shared platform.

In Case 1, the structural department is responsible for producing the bill of quantities, component drawings and reports. The **Bill of quantities** describes lists of items giving detailed identifying descriptions and firm quantities of the work comprised in a contract. The **component drawings** describe the key details of structural elements which are necessary for contractors and manufacturers. Finally **reports** are information related to sustainability strategy that designers applied in material adoption and technological aspects in construction, details of residential design development and construction risks, site survey reports which describes ecological survey and invasive plant growth survey, geotechnical reports that describe the ground and groundwater investigation, Cone Penetration Test (CPTS) & Standard Penetration Test (SPTS) and contractor policy documents including health and safety policies. The structural department in Organisation A also works on civil engineering projects such as highways and bridges. In these types of projects the initial information requirements are different from Case 1. The initial information requirements in civil engineering projects are topology drawings from ground, traffic information and river investigation reports. Regarding this issue interviewee SSE4 expressed as follows;

> "*…The level of details increases at each stage, let's start with conceptual design, probability not lot of money spend in data, data would be available and exist in maps, and they might be available from internet. So we can take the topology from the ground. As project goes on it would be more sophisticated. So in the M-Gate scheme we did ground survey which was taken by airplane and so quite a lot of details were gathered from the ground. Site investigation and river investigation was done by the team and reported…*"

Four out of a total of six interviewees (SSE2, SSE4, DM1 and BM1) stressed that it was a challenging task to manage the Case 1 documents as multiple participants produced an array of files in different formats. The interviews highlighted the following factors which are required to be complemented in their file/document electronic management system. Firstly, five out of six interviewees (SSE1, SSE2, DM1, SSE3 and BM1) declared that it is very important for their document management system to notify other disciplines whenever a participant changes any information in a file which has been published in the shared platform (**User Notification**). Secondly, four out of six interviewees (SSE1, DM1, SSE4 and BM1) argued that their electronic file/document management system should enable mobile access to information anytime, anywhere (**Simplify Access**). Thirdly, it is evident from four out of six interviewees (SSE2, SSE3, SSE4 and BM1) that their electronic file/document management system should allow selected files to be securely viewed by an external party who is not a participant in the Case 1 Internet shared platform (**Third party secured access**). And finally three out of six interviewees believed that their file/document management system is not a fully integrated system and it should allow users to search all project documents such as CAD drawings, texts, spread sheets and emails in the shared platform and keep track of what has been sent to whom, when and why (**Integrated search function**).

So far the focus was on analysed structured file/document management, and the next level in Case 1 is to consider unstructured data management. Five of six interviewees (BM1, SSE1, SSE3, SSE4 and DM1) claimed that there is a lack of an efficient system to manage unstructured data in their organisation. There are several forms of unstructured data in Case1 including texts, sounds and images. The unstructured data are found in **video conference**, **telephone conversations**, **meetings**, **emails** and **reports**. Emails and reports are more structured than video conference, telephone conversations and meetings, due to the fact that emails and reports can be identified by name, sender and time attributes. Regarding this issue, interviewee SSE1 expressed as following;

> "*…I can say that the vast majority of data in our organisation are not created in a clear format. Those are not like excel sheets, there are no rows and columns and those data are not tidy. When you want access to this information you need to spend a lot of time and some voice data might be missed during the meetings or telephone conversations. It is very tricky to get value out of these types of data.*

Yes it's messy to get out, it's hard to get out, however this data contains extraordinary important information..."

BIM Semantic Web Tier

In Case 1, a massive demand for information through fragmented disciplines is being faced. However, the information generated within the organisation or that are created by external stakeholders do not help Case 1 to reach its full potential. Access to the web links is also needed. Four out of six interviewees were of the opinion that there are increasing demands for information which are produced not only by humans but also by machines through web links. For example, interviewee BM1 expressed as following:

"...Historically data was being generating by workers. Employees from our company generate data but then the work involved internet and now users could generate their own data. Then the amount of data in the interest is increasing in comparison to the past. Recently there is another level of data creator which is machine. Machines can measure CO2 in site, analyse sustainability performance, there are several satellites around the earth that are taking measurements…"

Five out of six interviewees (BM1, SSE4, SSE3, DM1 and SSE1) expected that web of meaning should be employed in the Case 1 to accelerate information management procedure. Majority of interviewees held the view that developing web pages into meaningful structure helps the structural engineering discipline to achieve a better understanding of the issue as different disciplines and different professions have different understanding of an issue. The structural engineers and architects in the Case 1 project utilized different terminologies for description of some elements hence it leads to the use of different characters for same element in detailed designs. There are various disciplines in the Case 1 project and those disciplines often encapsulate information into graphical document such as AutoCAD or non-graphical such as texts. By applying meaningful web links between documents and the participants in Case1 project, Case 1 project can achieve **information-driven service**. Interviewee BM1 expressed opinion related to their requirement to information-driven service as following;

"…*In our project, most of the data is shared on extranet platform and this system is like a document based system which can be run in vertical flow. There is* ***lack of access to the meanings of the documents*** *is our project…*"

Four of the six interviewees (SSE1, DM1, SSE3, and BM1) pointed out that in addition to the meaning of the contents in the documents; **keyword search** is another challenge that may be addressed by a semantic web environment. Although it is possible to search words through stored documents or files in their extranet platform, there is a lack of an efficient search engine in their system that can enable users to search by using their own words to describe the keyword. For example interviewee BM1 expressed as follows regarding to this issue;

> "*…We do not have a web of massive data. We cannot fully control on our data, every software and application produce their own data and maintain these data in their domain. Our search engine platform needs to be facilitated by intelligent applications to enable content searching inside the data…"*

Four out of the total six interviewees (BM1, SSE1, SSE2 and SSE4) argued that their extranet platform could be designed like a blackboard that is linked to their company website. Each project participant could have his/her personal channel for accessing into the information repository on the backdoor of the website. The personal channel can be authorised by imitated domain access for each user. Therefore semantic web technologies can act behind the scene, in other words it will not impact on the browser appearance. Using **various terminologies** is another concern in managing unstructured data in the Case 1 project. Different people from different disciplines communicate by different terminologies to Case 1 participants. In Case 1 project when multiple words have various meanings then categorising documents in correct title would be an issue and in addition searching the relevant context will also be a another issue.

BIM Software Adoption Tier

The interviewees unanimously held the view that their organisation follows the AEC industry in selecting structural engineering software. They stressed that the decisions are based upon software that has been in use in the structural engineering industry for years. Thus a certain level of knowledge has been built up using that type of software. In this context, interviewee SSE3 expressed the following opinion "*Some of the software is government body industry standard. I think generally, thing like CAD the AutoCAD is now the industry standard so I think that we* ***follow industry standard*** *on that".* Majority of the interviewees believed that following the industry was not the right method for the Case 1 project. Their company needed to have some agenda for adopting the right software to increase the quality of information.

The commercial software that was used in Case 1 included planning software, analysis and design software, and software for viewing models. This research recognised that most of the commercial software which had been adopted in Case 1 was related to the detailed design phase and there was a **lack of software for the conceptual design phase.**

This research asked the interviewees to categorise the most important criteria for choosing the right software to increase the level of information quality in their organisation. The first criterion revealed from the statements of the interviewees was the **compatible version of the software**. Five out of six interviewees (DM1, SSE1, SSE2, SSE3 and SSE4) argued that when software vendors develop a new version of the software, their information management system would face a lot of challenges. In most instances the newer versions have massive differences with the older versions of the software and this leads to a loss of information.

From the interviews conducted in this study, the second most important criteria for software adoption in the structural engineering industry was found to be the availability of wide **product libraries**. Four out of six interviewees (BM1, SSE1,SSE2, and DM1) claimed that, structural engineering software with broad variety of product libraries or which are eligible to access online product libraries are more efficient in the course of information quality. The final factor that four out of six interviewees indicated referred to **online collaboration capabilities** of the software. Interviewee SSE1 expressed his opinion about this issue as follows;

"This sort of software is like the communication system, a part of sort of standard world office software which is pretty form of industry. Previously I mentioned about online collaboration software and they are often specified by clients, so on the business park scheme, our company preferred collaborative system online so we used that for this project. So all the reports, drawings, schedules were uploaded electronically to the system"

Table 5-2 Technological BIM adoption in case1

Technology Type	Criteria	Text percentage	Participants References	Influence on
Visualisation	Performance Prediction	1.1 %	4/6	Accuracy
	Design optimization	0.9%	3/6	Accuracy
	Validating material and sizes	1.2%	4/6	Accuracy
File Format	User notification	3.1%	5/6	accessibility
	Simplify access	1.2%	4/6	accessibility
	Third party secured access	1.0%	4/6	Security & accessibility
	Integrated search function	1.0%	3/6	Interoperability
	Various terminologies	1.6%	5/6	Accuracy & accessibility
Semantic	Keyword search	2.3%	4/6	Accuracy & accessibility
	Access to meaning of context	1.8%	4/6	Accuracy & accessibility
	Lack of tools for early design	3.0%	5/6	Accuracy
Software	Compatible Version	1.4%	3/6	interoperability
	Follow industry standard	1.1%	4/6	Accuracy, accessibility & interoperability

	Online collaboration capabilities	1.0%	3/6	interoperability
	Early design facilities	2.3%	4/6	Accuracy & accessibility

To sum up, in this case study, four technology types were evaluated (Table 5-2) for their impact on information quality. These included **visualisation, file format, semantic** and **software**. **Visualisation** had influence on accuracy, and comprised of three criteria *performance prediction, design optimisation* and *validating materials and sizes*. Four out of the six participants held the view that performance prediction had a significant contribution towards information accuracy. Similarly, half of the participants felt that design optimisation influenced accuracy of information and another four of the six participants stressed that validation of materials and sizes affected accuracy of data. **File format** was an important consideration. It comprised of six criteria that affected different aspects of information quality. Of the six participants, five considered that information accessibility could be improved by *user notifications*; four felt that *simplifying access* would also help and another four held the view that *regular updates* of information would also contribute towards accessibility. Four out of the six participants were of the opinion that *third party secured access* would improve both security and accessibility. It was felt by three of the six participants that interoperability would be improved by having an *integrated search function*. In terms of accuracy and accessibility of information, five of the six participants stated that information quality could be improved by addressing the issues that result from the use of *various terminologies* by the different disciplines involved in the project. In terms of **semantics**, accuracy and accessibility of information were the main concerns. Four of the six participants felt that this could be improved by enabling a *key word search* and another four felt that having an *access to the meaning of the context* can also contribute. The use of appropriate **software** was a great concern. Five of the six participants felt that accuracy was compromised due to the *lack of tools for early design*. Of the six participants, three were of the opinion that interoperability was affected by the *version of the software* being used, and another three felt that interoperability could be improved by enabling *online collaboration capabilities*. Significantly, four of the six participants held the view that by *following industry standards* information accuracy, accessibility and interoperability would all be improved.

5.1.4 Human Resource Readiness and BIM Adoption in Case 1

Assessment of Case 1 in this study reveals that there are some issues related to human resource readiness which impact on quality of information. The first issue is related to **lack of key skills** in using recent BIM tools and standards between both senior and junior structural engineers and the second one is **lack of optimum training strategy** to prepare structural engineers to adopt BIM tools. Majority of the interviewees argued that the ever changing BIM commercial environment necessitates the requirement of a highly skilled and flexible workforce in their organisation. Therefore, based upon the opinions of the interviewees in this research, it was evident that Organisation A should modify its recruitment strategies by considering efficient criteria for hiring senior structural engineers. Moreover, this organisation should incorporate BIM training courses for graduates or junior structural engineers to increase the level of information quality.

In the UK, all large organisations have human resources management departments (HRM) that are responsible for employee resources. The design manager in this case mentioned that the objectives of staffing in their organisation to resource Case 1 project were not efficient. This research identified the significant criteria which interviewees in Case 1 believed should be taken in consideration before employing the structural engineers. Half of the interviewees (SSE3, DM1 & BM1) believed that the human resourcing strategy does not match with BIM aims and objectives in their organisation.

Interviewees highlighted challenges in the recruitment of structural engineers in organisation A which affected the quality of information in the Case 1 project. Firstly, five out of six interviewees (SSE1, SSE3, SSE4, DM1 and BM1) believed that most of senior structural engineers are very **reluctant to implement new BIM technologies**. For instance BM1 interviewee expressed that "experienced *structural engineers are hesitant to use BIM tools".* Secondly, four out of six interviewees pointed out that the **cost for replacing new employee** is too much in their organisation. In this context interviewee DM1 expressed the following "*recruitment of new staff always cost us too much".* And finally three out of six interviewees (SSE2, BM1 and DM1) believed that **job description** for the new graduates or junior structural engineers are not expanded to include basic skills and competence to use the BIM tools.

This research asked the interviewees to describe their human resources function in the Case 1 and also to recommend efficient human resources recruitment strategies for their current structural engineering project (Case 1) by considering BIM tools and workflows application to increase the level of structural engineering information quality. This study reveals that human resources recruitment function in the case1 has been conducted through the internet. The interviewee DM1 pointed out that 80% of the employees in Case 1 posted their CV on job hunting agencies websites or through the social media such as Linked In. In this context four out of six interviewees (BM1, SSE2, SSE3 and DM1) believed that in this stage job adverts on the Internet play very significant role to attract the relevant structural engineers who have the ability to adopt BIM and increase the level of structural information quality.

All of the six interviewees (SSE1, SSE2, SSE3, SSE4, DM1 & BM1) pointed out that structural engineering industry is very competitive job the market in the UK. Each organisation or department among organisation has their own criteria to seek the required talents. This study reveals that in the case1 project candidates filled the job application online and as shown in Table 5-2 and further discussed in the following paragraphs increased the chances of accepting candidates into interview process.

The first criterion for considering job application was **Education**. In this project undergraduate and graduate degree in civil engineering, structural engineering, construction management and BIM were effective criteria for recruiting applicants. All of the interviewees argued that although university degree had significant role in accepting them into interview process their technical knowledge and IT knowledge in structural engineering and construction domain were considered effectively by human resource administrators. In this context interviewee BM1 pointed out that " *BIM software application were perceived in my online curriculum job hunting*" In the case1 human resource recruitment online job application, relative course works which graduate applicants have done in universities have been considered. **Integrated design course works** and **BIM course works** have influenced application process very positively.

The second criterion for considering job application in case1 was **experience**. Five out of six interviewees (BM1, DM1, SE1, SE2 and SE3) pointed out that their department which is implementing case1 project is trying to require for technically skilled design professionals with regard to BIM. In this context interviewee SSE2 pointed out that "*My job application was extremely affected by my previous experience which I archive working in integrated* *structural design environment"*. This case study reveals that Case 1 for facilitating human resources in the case1 project focused on structural engineering experiences domain. Nevertheless, overall most of the interviews felt that **knowledge in BIM software application**, **BIM concepts and BIM standards** would impact on information outcome from their department. Most of the interviewees (SSE1, SSE2, SSE3, SSE4, DM1 and BM1) were of the opinion that experienced senior structural engineers who have experience working with BIM software applications, who are aware of concepts in adopting BIM and BIM standards will increase the level of accuracy, accessibility, interoperability and security of information in their current project.

Table 5-3 Human Resources readiness BIM adoption in case1

Human resource readiness strategy for implementing BIM	Criteria	Text Percentage	Participants References	Influence on
Recruitment **Senior structural engineers**	BIM software application skill	0.3%	6/6	Accuracy Accessibility Interoperability Security
	Knowledge of BIM concepts	0.35%	6/6	Accuracy Accessibility Interoperability Security
	Understanding of BIM standards	0.4%	6/6	Accuracy Accessibility Interoperability Security

Training Junior structural engineers	Conducting BIM internships	0.35%	6/6	Accuracy Accessibility Interoperability Security
	Defining role and responsibilities for BIM manager	0.25 %	4/6	Accuracy Accessibility Interoperability Security

As pointed out by majority of the case1 interviewees (SSE1, SSE2, SSE3, SSE4, BM1, DM1), Case 1 need to provide internal training in BIM technologies and integrated design environment. As it has been shown in Table 5-3, two major issues were identified related to human resource readiness to adopt BIM and these were **recruitment senior structural engineers** and **training junior structural engineers** of structural engineers. Recruitment of structural engineers was significant consideration and impacted information accuracy, accessibility, interoperability and security. Three important criteria were proposed to address this issue and these were *BIM software application skills, knowledge of BIM concepts* and *understanding of BIM standards.* All the six participants expressed that during the recruitment of senior structural engineers, the job requirement should specifically include these three criteria. It was felt that training of structural engineers would also have a positive impact upon information accuracy, accessibility, interoperability and security. To address the issue of training, it was felt that two approaches may be used and these included *conducting BIM internships* and *defining the roles and responsibilities of the BIM manager*. All the six interviewees held that conducting BIM internships would greatly help junior structural engineers hone their skills in BIM technology. It was felt that training on the functional aspects of BIM technologies could be imparted in a short internship programme. Four out of six interviewees believed that defining the roles and responsibilities of the BIM manager can contribute information accuracy, accessibility, interoperability and security very positively.

5.1.5 Case1- Findings and discussion

Case 1 is a conceptual and detail of structural design of a Hospital project in organisation A. The key organisational success goals in Case1 are outlined under team working and collaboration with other internal and external disciplines. Although Case1 had access to efficient budget and resources for adopting novel information and communication technologies, information quality dimensions were the critical challenges in information management in Case1. The literature review (Section 2.2) indicated that information interoperability, accessibility and accuracy are the key challenges in AEC industry and structural engineering discipline. As a result the findings from Case1 indicated that the key information management challenges are interoperability, accessibility, inefficient tacit knowledge repository, lack of communication and information security.

Technological, workflows and human resources readiness are the domains of BIM which are investigated in this research. The review of literature review leads this research to categorised technological contribution of BIM to structural engineering under visualisation; file format & standards, semantic and software. It is revealed from Case1 that "performance prediction", "design Optimization" and "simple model simulation" are the key criteria that need to be considered while adopting efficient tools towards enhancing accuracy of information in the visualisation tier. The findings from Case1 showed that the key criteria in adopting tools under file format and standards tier are: user notification, simplify access to information, third party secured access, integrated search function and various terminologies. The majority of participant's opinion held the view that by considering these criteria the level of information accessibility and accuracy can be enhanced in their project (See section 5.1.3 for more details). The Caes1 findings shows that key word search, access to meaning of context and lack of tools for early design are the key criteria in adopting semantic technologies towards enhancing accessibility and accuracy of information. The fourth BIM technological tier under Case1 investigation was conducted under the software context. The findings show that adopting BIM-based software can contribute to accuracy, accessibility and interoperability in structural engineering. It is also recommended that structural engineers consider compatible versions of software and do not follow the industry for adopting software without having agenda for adopting the right software. The product libraries and online collaboration capability of software also impact on information quality.

In the BIM workflow adoption domain, literature review identified relevant BIM based workflows that are not specialised for structural engineering requirements. The findings from

Case1 highlighted key criteria that are recommended to be considered by structural engineering organisations for adopting available workflow or create their own workflow to enhance information quality. The Case1 shows that efficient workflow should be developed under three main information management processes; information producing, information sharing and information evaluation. The evidence from case1 indicates that document control system (in information producing phase), updating structured information regularly (in information sharing phase) and remote control comments (in evaluation phase) can dramatically contribute to information quality. The findings from Case1 are emphasised on recruitment and training as two critical factors for adopting BIM. Literature review suggested internships and universities courses for making human resources ready for BIM adoption. The Case1 indicated that BIM software applications skills, knowledge of BIM concepts and understanding BIM standards can contribute to enhance information accessibility, information accuracy, information interoperability and information security in the structural engineering discipline.

5.2 Case 2- Qualitative Data Analysis

Two cases that have been investigated through interviewing relevant participants have already been discussed in this chapter (Chapter 5). The participants had responded to questions pertaining to their ongoing projects. In this chapter, qualitative data analysis has been carried out with the aim to discuss and comprehend the opinions of the interviewee in the context of the challenges in information management in their current project and the possible solutions that may assist in improving the information quality in each case. Prior to the commencement of the qualitative analysis of this study, thematic coding scheme had already been applied. This coding system comprised of two categories: Context and Keywords. Further refinement of the earlier conceptual framework (See Figure 3-14) was done by using the context and keywords that had been finalised from both cases. Data, after collection and recording was sorted out into themes. These themes provided the storage areas in NVivo for accessing coded text. The key words have been categorised into relevant themes as presented in Figure 5-2.

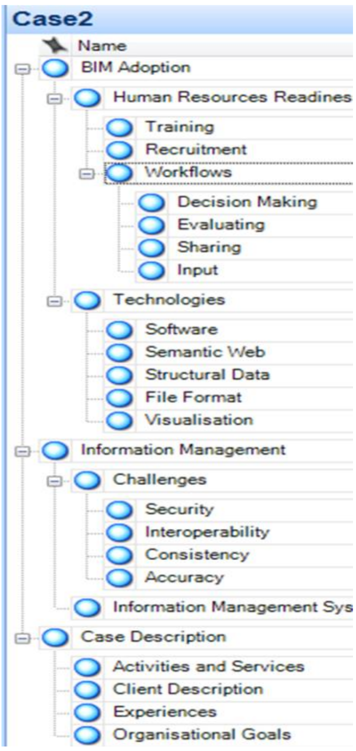


Figure 5-2 Themes of Case2 from NVivo

5.2.1 Case 2 Description

Case 2 was sourced from an ongoing project in a structural department that forms part of the design in Company B. As a multidisciplinary independent firm of architects, engineers and contractors, Company B offers a wide range of AEC services. Founded in 1946 in London, Company B initially focussed upon structural engineering. The core aim of decision making in Company B is ***sustainable construction***. Client requirements and commercial imperatives form the next level of priority in the decision making process. The projects of Company B are now extending beyond the construction industry. This is reflected in the focus on computer modelling tools that are used for both internal projects and are being developed for sale all over the world. The organisational strategy was reflected in the responses of most of the interviewees who held the view that innovation in the adoption of efficient methods of design, the adoption of novel technologies and team work were crucial for survival in the tough AEC industry in the UK. For example interviewee JSE7 expressed that;

> "…*What excites me in working in this environment is the opportunity to create better structural buildings than before by utilising novel design methods and novel technologies"* and interviewee SSE8 pointed out that "*In our department we deliver projects by team and nothing is delivered individually and this is the key point to success in the difficult AEC economy..."*

Majority of the interviewees, five out of the six interviewees (SSE5, JSE7, SSE8, DM2 and BM2) underscored that the objectives of building safety, health of people, sustainability, and design economy are of paramount importance in the structural engineering department of Company B, and that these objectives are kept in mind while considering the expectations of the client. For example interviewee SSE5 mentioned that with regard to this issue,

> *"Our Company likes challenges; the objectives in our structural design department are to create buildings that are safer and healthier. We bear in mind that every decision will impact several issues that are related to the environment, lifestyle, culture and the economy".*

In the context of client requirement, interviewee SSE8 stressed that;

"The challenge for us is to ensure reliable delivery to our client and to exceed the expectations of the client, and to achieve this we need to cross our own boundaries."

Case 2 that has been investigated in this research focussed upon the structural engineering information management of a multi-purpose arena with 15,000 capacities in the centre of Ørestad, Denmark. This arena would form a local, regional and international centre for sport, cultural and entertainment events. A flexible configuration of events and spectators was considered by the architectural designers of the project, and, the UK office of Company B carried out the structural engineering design.

The operational functions of Company B include structural engineering design, civil engineering and construction disciplines. The conceptual and detailed structural information management of the arena project in Company B has been studied in Case2. The main client was represented by Arena CPHX and the project was a joint venture between the city of Copenhagen and Realdania. It was expected that the arena will be operation at the start of 2016. The building was planned to have an open ground floor and a plateau for public access at the first floor. Cost projection of the project was at 43,000,000 Euros, and most of the budget was granted by Realdina Company and the city of Copenhagen. Additionally, a conditional fund up to DKK 15,000,000 was provided by the Danish Ministry of Culture (ArenaCPHX, 2013).

5.2.2 Information Management Challenges in Case2

This section has focussed upon gathering the responses of the interviewees from the structural engineering department of Company B in relation to the information management processes and challenges encountered during the Case 2 project. The respondents from the second case study gave a detailed picture of their information management features starting from the receipt of drawings from the architects to the last step of their activity wherein they provide information for construction purposes. Challenges encountered in managing information during this particular project were also elucidated by the respondents. Step by step extraction of meaning from the transcriptions of all the six interviewees in case2 yielded the key challenges faced and these have been highlighted in this section.

5.2.2.1 Inputting Information into Structural Engineering System

Majority of the parameters describing space, structural zones and structural elements were provided by sketch drawings by the architects in the Case 2 project. Further information from other disciplines needed by the structural engineering department depended upon the particular project. In the Case 2 project (Arena project) for example, the structural engineering department requested for a lot of information in the initial stage of information management (input information stage). This information included for example site specific issues and soil type contamination. All the input information was provided in 3D architectural models, texts and 2D general plan of the map. Interviewee SSE8 stated as following.

> "*…We get information from the architect as the geometry of the building. We get 3D information about shape of the building, the overall form of the building, which is plan layout and whole…*"

Interviewee SSE6 indicated that more information was needed during the input phase and in the Arena project the site constraints included two issues and these were site specific issues and soil type contamination.

> *"...The only thing I needed in my task was site specific and just the general location on the map..."*

A number of meetings and brainstorming sessions among the structural engineering department team, members of other design disciplines and client were held during the conceptual feasibility stage of the structural engineering process. Several modalities of communication were used to carry out these meetings such as face to face discussions, phone calls and video conferencing. In this context, intervieweeDM2 pointed out as following;

> "*..I think that most of the time the input is in the form of drawings and the majority of these are CAD drawings. In most instances they are provided by the architect, but sometimes they may be sent from building services. It can also be sourced from other Arup teams such as Health and Safety team and so that it is the majority. A lot of information is also yielded by the meetings. In the case of the Salford job that I was involved in we held meetings with the architects and discussed the best structural arrangements, and in the brainstorming sessions we thought up of ways of structural design solutions and put in the Revit model and we updated the Revit mode…*"

Furthermore, interviewees DM2 and BM2 mentioned that in the arena project more information was needed as the initial input submitted by the architect was very vague and unclear. During the meetings, the conceptual design brief was developed by having a clear understanding of the requirements of the client and the technical points of other disciplines.

The conceptual stage of design was followed by obtaining the 3D information from the architect. This consisted of the geometry of the building including the shape and the overall form of the building, the plan layout, whole envelope, loading requirements and space description in terms of purpose of usage. In this context, it was pointed out by interviewee SSE5 that:

> "*…I guess that most of the information that we get from the architect has to do with the finishes, how everything looks. We get performance requirements such as for example, acoustic performance requirements to stop noise breaking. For the Copenhagen project, we got some loading requirements from the architect, and the operator provided information on how they wanted the space to be used…"*

The structural engineering department coordinated with some local offices in Copenhagen to obtain some more information regarding to available materials in the country. Hence the conceptual design was provided with all information which was input in the conceptual design stage. In the Case 2 project Euro codes had been applied as standard design guidelines. In this project both client and third party reviews were carried out. In this regard, it was pointed out by interviewee SSE6 that:

> "*I think, other input was provided by the structural design team, so we are looking at the type of materials available in the country of operation. The local offices provided us with advice regarding the type of steel available in Denmark. We also got other inputs such as the Euro code. So we took all these design codes and other inputs from third parties. Moreover we had third party reviewers and reviews by the client, and their comments were taken as further inputs. Finally, the experience of our design teams also contributed to the inputs to the design"*.

Case 2 revealed that about 75% of the input into the structural engineering information system is in the form of drawings that are presented in the Dwj and PDF formats. A further 20% of the input results from meetings. Five out of six interviewees (SSE5, JSE7, SSE8, DM2 and BM2) indicated that most of the verbal information incorporated in the structural engineering information system was by meetings and only 5% resulted from telephonic conversation. In Organisation B the capture of content during meetings and its accurate retrieval into the information system is very important for the structural engineering team. Majority of the interviewees pointed out that **maintaining telephone, email and video conversation information is more critical** as the information enclosed in these tools are captured by the individuals and the risk of missing and inaccurate information is likely to be more than group capturing information. For example interviewee BM2 pointed out that:

> "*…So minutes of meetings tend to be maintained as you capture and what happens in the meeting. It is just capture to the document and circulation to the team. But the problem with telephone and email conversation is capture of information by the individual and taking responsibility for the same…"*

The structural engineering system received information package as described. This information has been provided by various format input on the shared system platform. This shared system platform has two major proficiencies that are the information access portal and the information transfer portal. The information access portal serves as the connection between the users and the information management system, and it allows users to communicate with the central system for uploading, downloading and searching for files. The information transfer portal on the other hand, is the connection between the internal data base centre and external users, and this has connection that is authorised by certain security access limitations. Majority of the interviewees (SSE5, SSE6, JSE7, SSE8 and DM2) expressed that their shared information system platform had been designed according to the requirements of Organisation B and by applying this system lots of challenges regarding to missing information have been addressed. Nevertheless **there are no workflows or any strategy for training users to learn the efficient way of using this system**. The responses from the interviewees (SSE5, SSE6, SSE8, and BM2) emphasised that the digital information produced in conceptual design project including 3D models, text files and photos were stored with description into the shared platform. Hence, users can access that information anywhere and at any time. However, that **information was not linked to each other**.

5.2.2.2 Producing Information in Structural Engineering

As stressed by the respondents, analysis and design are the two main engineering procedures conducted in the structural engineering department. In the analysis phase, the structural engineers would calculate the loads and geometry of the components. The responsible elements in the model would be determined in the analysis phase, and in the ensuing design phase, the size of the model would be calculated with respect to resistance to applicable forces. In this context, interviewee JSE7 stressed that;

> "…*There are two real processes, one is analysis and the other is design. We take the loads and geometry and carry out an analysis which tells us about the various responsible elements in the model and provides guidance to design these elements that are resistant to those forces…"*

It was accepted by most interviewees in the Case 2 study that "engineer judgement" impacts upon the results of the analysis and design processes. Package of information received by the structural engineering department is filled electronically in the system by the engineers who mention that it is scratched or drawings or whatever. Hence, the structural engineers in the team are aware of the location, name and description of the information. Based upon the organisational requirements, software applications have been developed in Organisation B that conduct the analysis and design process. Technical information for construction purposes is captured from calculation and construction planning and the processed information is captured on the reports.

Lack of both **information accessibility** and of **information accuracy** were the two main challenges faced during the analysis and design process in Case 2. This was reported by most of the participants (SSE5, SSE6, JSE7, SSE8, DM2 and BM2), who also felt that there are two main approached to ensure information accessibility. The first approach is to protect stored information in the system against disasters and the second approach is to input valid information into the database system. No serious concerns related to backup of information were revealed in the Case 2 study. However, the participants were not satisfied with the completion of valid information while editing the information.

Of the six interviewees, five (SSE6, JSE7, DM2, BM2 and SSE8) pointed out that in the case2 project; a mixture of information from other disciplines was captured in to the structural engineering department system. As most of the information captured from the meetings was in the form of dialogue and hand sketches, the main challenge was misunderstanding at the time of transcription of that information in the system, and this was referred to as **inaccurate information**, and this would lead to errors in the results. With this aspect in mind, interviewee BM2 pointed out that;

> "*…There is a mixture of information received, and perhaps the most valuable information is captured from dialogue and hand sketches. It becomes imperative to develop an understanding of the information collected…"*

Moreover, interviewees SSE6 and DM2 pointed out that manual calculation and the experience of engineers can play a very significant role in the level of accuracy of the information in the analysis and design process. For example, interviewees SSE6 expressed as following:

> *"I think it is very interesting that sometimes you get results very quickly and you get estimates and simplification that helps achieve a great degree of sophistication. For example, when we did a concept design on the arena roof and were going through 25 snow loading cases, it happened that we already knew 1 or 2 from past experience. This would give us an answer. So, I think that a degree of manual input and experience should be included in the process rather than to input the information automatically"*.

5.2.2.3 Exchanging and Sharing Information in Case 2

Information was delivered to the client, contractor and other AEC disciplines in the case2 project by emails. Most of the information shared was in the PDF format, and was categorised into drawings and reports. Drawings comprised of information on structural zone, structural frame and structural components with details. The reports consisted of calculation plan that had been captured from software and manual calculations, assumptions of building works, materials and sustainability system, concrete specification and would also specify any special requirements and resistance disclosure. In this context it was stated by interviewee SSE6 that;

"…S*ometimes information is shared with emails and usually the format is PDF. Reports differ from drawings. In a typical project we have a calculation plan, have assumptions, inputs and outputs and for the design processes we use specific software's such as for the way the building works, what materials are going to be used, what are the sustainability systems. However, none of the information is sufficient for designing the building. So we have concrete specifications that tell us about any special requirements and resistance disclosures or visual concrete…"*

In the Case 2 project, some reports were exchanged with the client that specified the geometrical concentrate of the project that contract has to comply with in the building. There are some performance specification documents that describe all the elements that might not be designed. For instance Interviewee SSE6 expressed as follows:

"…*We may not design stairs for example, we might say stairs need to perform to standards we talk about natural frequency of stairs. There would be lots of items balconies or mechanical and electrical stuff. Also drawings are separate from reports which again normally are in PDF…"*

Specific enquiries were made from the interviewees in case2 to find out if a document sharing system was used by Organisation B instead of merely exchanging documents. There was consensus among all the interviewees that File Transfer Protocol (FTP) System has been used in some projects in organisation B. FTP is a protocol to share document from one host to another host over the internet network. The Three out of six interviewees (SSE5, DM2 and BM2) held the view that the **issue with using FTP is that there are several host addresses and there is no standard one**. The addresses change in different times. For example interviewees SSE5 pointed out that:

"…*If we have a small job then we usually use emails to send the files, but sometimes when the clients have their FTP in internet we would use e-share. The problem is they are different and everyone wants to use their own. I say there is no standard one, it's different every time. In Arup we have FTP.arup.com which we can use…"*

The briefs come from the clients and are normally delivered to structural engineers personally from project manager or project director. It may be a document that can be circulated to the designers, if any one wants to know about the project requirements. Architectural information are the key inputs in the brief documents, which come in the form of drawings usually, which again is provided to structural engineers from the architect or project manager or project director. Most of the participants agreed that a lot of time is spent in solving **interoperability issues** when drawing information was exchanged or shared with clients or local authorities. Five out of the six interviewees in case2 (SSE5, SSE6, JSE7, DM2 and BM2) pointed out that:

> "*…sometimes when we are working in international projects, we need to comply with local regulations and these are input into the brief as well. Sometimes, we need to look at that information ourselves or need to hold meetings authorities to establish the requirements needed. As that information is provided by the local authorities or the client, we have to understand what the requirements are. They might also be particular operators for buildings that they have their own requirements in addition to developers that actually build it and it has to be taken on board…"*

> "*And then we get further and further into design process, the great deal of information flowing between different designers so as well as architects will be building services engineers, it might be landscape architects and might be specialists in fire engineering, some might be internal and some might be external."*

Seven challenges had been identified in this study of the case2 project and these are being illustrated in the Table 5-4. These challenges included: Information accessibility, Information accuracy, Information interoperability, information security, unstructured data, lack of workflows for training staff and lack of linkage between information. All the six interviewees rated information accessibility as a very high challenge for information management and 3.5% (See Table 5-4) of the transcribed text from interviewees' voice, talks about information accessibility as a very high risk in case2 information management. Of the six participants, five indicated that information accuracy and information interoperability are very high challenges and 6.8 % (See Table 5-4) of the transcribed text from interviewee's voices is refers to Information accuracy and information interoperability as very high challenges in the context of information management in Case2. Information security, unstructured data (mostly maintaining telephone, email and video conversation information), lack of workflows for training staff and lack of link between information have been rated as lower challenges in the Case 2 information management system.

Table 5-4 Information management challenges in case 2

Information Management challenges in case 2	Text percentage in transcription	Participants References	Rate Challenge
Information Accessibility	3.5 %	6/6	Very High
Information Accuracy	3.4%	5/6	Very High
Information Interoperability	3.4%	5/6	Very High
Information Security	2.0%	5/6	High
Unstructured data	1.6%	4/6	High
Lack of workflows for training staff	1.6%	4/6	Medium
Lack of linkage between Information	1.0%	3/6	Low

5.2.3 BIM Adoption in the Case 2

Most of the interviewees were of the opinion that BIM should be implemented in their organisation with a consideration towards three main dimensions which are *choosing the right technological tools*, *business workflows* and *human resource readiness*. In the case2 study the opinions of the participants closely reflected the findings from the literature review. It was argued by five of the six interviewees (SSE5, SSE7, SSE8, DM2 and BM2) that the quality of information needed for decision making in organisation B can be improved upon by incorporating BIM. Moreover, they also held the view that in Case 2 more efficient methods of enabling technology could be adopted with the potential of trained human resources for improving the information produced and for better communication within the discipline partners. The following sections have been devoted to the examination of the technological tools that have been adopted for implementing BIM in structural engineering information management in Case 2. The technological aspects studied have focussed upon **visualisation, file format, semantic** and **software adoption**.

5.2.3.1 BIM Technologies Adoption in Case 2

The interviewees of Case 2 held the opinion that successful structural engineering business would distinguish technologies to aid engineering code and decode information in more constructible and accurate presentation. Structural engineers require using tools and services to enable them to present shapes, present quantities, and present the performance to facilitate decision making in construction phase. In the decoding phase of structural engineering information management Case 2 participants required to understand the geometry of information which has been described by the architect. Structural engineers are required to understand the location of the elements (column, brace etc.), the location of elements to each other, the size of the elements, the spaces, the intended use of spaces, materials and the environment in which the element would be located. For example interviewees SSE7 expressed as follows;

> "*…We need to understand the geometry which is by the architect so we need to know where is the column, where is the brace, how tall is the building and we need to know the intended use of rooms and materials, and these are architectural ambitions. Lastly we need to know in what environment is the element, such as whether there is shelter, boxing or sealing types, external elements…*"

Subsequent to comprehending the data presented by the architect, simulation of data was started by structural engineers in case2. Five out of the six interviewees (SSE5, JSE6, SSE7, SSE8, BM2) stressed that in coding or simulating data '**simplification**' is a very significant factor. Several advantages of running simulation after simplifying data were perceived by these interviewees. During structural engineering education several formulae are developed to present the complex reality in simple terms, however, in actual industry practice engineers faced complex shapes of elements (The Final Element Analysis method has been applied in Case 2 to divide complex domains into small pieces to solve easily). Hence in the case2 project, emphasis was placed upon simplification simulation.

It was revealed in the Case 2 study that simplified models help to **predict the performance or behaviour of product** more accurately. Simplified model could help engineers gain a better understanding of the circumstances and they could use their engineering judgement to take better decisions about the behaviour and reaction of particular structures to their specific circumstances. During the simulation phase, the geometry of the structural model and its surrounding environment is determined by the structural engineers. The most important factors of surrounding environment are loading, temperature and humidity which should be simulated in the model. The most significant performances factors that structural engineers require to predict are displacements of the elements and durability of elements.

Three out of the six interviewees (SSE5, SSE7 and SSE8) expressed that from the view point of model visualisation, **presenting critical zone** can play an important role in performance prediction factor. For example interviewee SSE7 stated that; "*The important fact is when we are running the result we need to recognize the critical zone to make sure of our model resistance and reaction*". The most critical zone is that part of the structural elements that are under most stress conditions or most displacement. An efficient structural visualisation should distinguish the critical zones and the reaction of those zones to the environment.

Design optimisation was the second factor except predicting performance that was highlighted in Case 2. Overall, there was unanimous agreement among all the interviewees that visual results from simulation model should help engineers consider other solutions and alternatives. In this context, interviewee SSE8 expressed that; "*And then you draw the project more efficiently. So you may come back to alternative solutions. I mean sometimes that would be big changes like value engineering changes when the contract comes on board you need to start again and sketch from basic. So that there might be changes of material because the contract does of availability*". In Case 2 project there was a lack of technological view point when structural engineers obtain results from simulated model under simulated environment to observe the alternative materials and optimized size of the elements.

From the view point of the BIM technology, the second tier enquired in the Case 2 study is **File Format Management**. Stakeholders involved in the Case 2 project faced the complexity of dealing with hundreds of files in different formats. The various file formats that are were used in Case 2 included: text files (Microsoft Word), PDFs, 2D CAD drawings, 3D CAD drawings, images, spreadsheets and RFI. The text files and PDFs were used for presenting reports and 2D CADs were used for presenting shop drawings to contractors, as most of the interviewees indicated that contractors and site engineers prefer using 2D drawings and Dwg format. Most of the interviewees stated that they rarely or occasionally model with 3D formats. The interviewees in Case 2 believed that people do it inaccurately or expect certain accuracy by others to deliver 3D drawings correctly. For example Interviewee JSE6 expressed as follows:

> "*…It could be any of those. So we receive photos that show that there is a clash between foundation and column. I receive RFI that says the dimensions between drawings or we might review spreadsheet about pile design or could be word document or PDF. Normally our drawings are PDF sometimes we issue with Dwg rarely or occasionally we model with 3D models…*"

Images were used by structural engineers from Case 2 to present conflicts between the foundation and the columns. They used spreadsheet files for describing piles numbers and loads in big schedule to the client. Interviewees mentioned that they converted some information from Revit software into spreadsheet format to present to their client. Interviewee SSE7 expressed as follows:

> "*…If we issue photograph then we have http site in our company and if we issue reports then it would be in PDF format. Normally we use excel sheets for pile numbers and loads in big schedule and if the client wants it in excel format then I personally convert it from Revit to excel and send it to them saying that as I have converted it by hand so it needs to be checked for accuracy...*"

It was stated by the majority of the interviewees from Case 2 that their organisation seeks to develop a simple way to manage engineering files and data. Of the six interviewees, five (SSE5, JSE6, SSE7, BM2 and DM2) emphasised that structural engineering drawings and related data need to be **simplified accessing** to enable for revision of documents available wherever and whenever those are required. Case 2 reveals that their file management system should be facilitated to enable corporation between disciplines to **determine their requirements**, **tracking data** and change data. Overall, all the interviewees emphasize that it is very critical while a piece of information being changed or eliminated from the system, and the system should **notify users**.

Participants from the Case 2 study described a shared intranet platform for uploading files in organisation B that has been designed for internal access. Online cloud facilities such as google drive and Dropbox are used to share structural engineering information with external stakeholders such as clients, local authority and contractors. Majority of the interviewees felt that fragmented sharing of information on both offline and online platforms creates a number of issues in delivering information to third parties such as clients and local authorities. From Case 2 it can be inferred that in most instances the document management systems between structural companies and third parties are not matched together causing inaccessibility of information. Hence **third party secure access** is one of the important factors in file management system in structural organisations. For example Interviewee BM2 stated that:

> "*…Information sharing with other parties is part of our business problem. We need higher quality of information delivery to our clients. Our clients sometimes can't find our files and they do not have document control over our files*..."

In Case 2, the database for the information system was designed after considering the following factors: *be available, be safe* and *be manageable*. The IT department of organisation B perceives that the database for this organisation has to be large in size, used by hundreds of users and should be available from fragmented geographic locations. Majority of interviewees (SSE5, JSE6, SSE8 and BM2) expressed that information queries from the database is another significant factor in structural engineering information management system. They believed that making a database available in searching data by its users is not easy. Hence most of the interviewees expressed that from the file management view point it is very critical to consider **integrated search function** and **Updating regularly** as factors which impact on availability of information, security of information, sharing data between different parties and accuracy of information.

The third tier of BIM technology as evident in the Case 2 study is **semantic**. In this part of case study of Case 2, the interviewees were asked to explain how they set and access to concepts and relationship between concepts among the structural engineering domain. By studying interviewee's opinions, it can be considered that structural engineering information in Case 2 project includes unstructured, semi-structured and structured data. The context of most of the structured information are readable by machine however, Case 2 participants need supporting tools to enable them to access the meaning of context or terms in unstructured or semi-structured information.

Part of the information required by the structural engineering department in organisation B is located in HTML syntax in the internet web page presentation layouts. On the other hand, the new generation of web services are designed by well-defined semantic languages which are called semantic webs. These webs enable the mark-up and manipulation of complex taxonomic relationships between concepts on the web. Interviewees held this view that they can find titles, figures, links and tables in their online and offline information system however they cannot find data by their meanings. The majority of interviewees expressed that their information system should allow the users to create their own tags. It will enable more efficient **key word search** and **access to the meaning of context** among information.

It was preferred by the BIM manager and design manager from Case 2 that unstructured information be tagged by their document description, time and related attributes and the meaning of contents in the document can be coded by RDF and XML tags. This method would help describe unstructured information that has to be processed by computer programs. It was also emphasised in the Case 2 project that in the structural engineering industry there is the same term of reference to different concepts. While structural engineers and other construction stakeholders would understand those terms, the IT programme is unable to distinguish the different meanings in different sentences. The BIM manager and design manager in Case 2 study have suggested that tagging different concepts by different URIs will **cover different terminologies** and it would increase accuracy and accessibility of information.

Software has been identified as the fourth tier of BIM technology from the view point of the Case 2. It is evident from studying Case 2 that although the structural engineering industry in the UK is keen to adopt new technologies, they would be unable to implement these technologies without having the opportunity to test and observe all the associated obstacles and risks. Keeping in mind the implementation of BIM in Case 2, most interviewees felt that the key technological issue is which software to purchase. However, Case 2 contrary to Case 1 does not follow the market for selecting piece of software. Three out of six interviewees (JSE7, SSE6 and SSE5) pointed out that in the Case 2 project an integrated piece of software had been used for both analysis and design phase. Although some of the structural elements were not as simple as previous projects, their in-company analysis and design software package modelled structural elements very simply and majority of the structural engineers were satisfied with the functionality of this package. For example Interviewee SSE5 expressed as follows;

> "…*The best pieces of the software can integrate both processes: do the analysis and based on the result of the analysis they do the design but the problem with that is often the structural elements are not always simple. If you have one beam in isolation then that piece of software is easy to use but when you have whole building with things interacting with one another the situation is different. So the software that we tried is clever and makes everything too simple I found it very rare that we were concerned in our project...*"

Overall, most of the respondents (JSE7, DM2, BM2 and SSE8) pointed out that in the Case 2 project, the structural engineering software package was developed in-house by the company's software engineers with respect to the requirements of the project. In terms of design, a variety of software which serves to integrate and address technical functionality issues were developed by organisation B by making use of the experience gained with each project. Therefore the **compatible version** of software employed in the case2 project did not reduce interoperability between the different versions in use. For example DM2 interviewee indicated as follows;

> "…*Of the wide range of available structural engineering packages, we selected GSA as it has been developed by our company. Several computer packages are available that have been developed by software professionals. In terms of design our company wrote a number of design tools which intend to integrate, and these tools sometimes give good results and sometimes don't do very well…*"

Interpretation of the opinions held by most of the interviewees revealed that the technical structural engineering calculations related to use of software package was not really a challenge in the Case 2 project. Four out of the six interviewees (SSE5, SSE6, JSE7 and SSE8) indicated they can check some calculations manually when there is not enough certainty and confidence in the results from the software. For instance participant SSE6 expressed that:

> "…*There are a series of independent calculation tools, and there are a series of calculations where all you have to do is to input the data and do simple checks. It is very prescriptive and so you have to assess whether the calculation result gets the*

answer and whether it is suitable for your design. If only one element is being evaluated then we calculate it by hand…"

It was expressed by some structural engineers in Case 2 (SSE5, SSE6, JSE7 and SSE8) that it is not possible to compensate errors in the conceptual design. They stressed that accurate conceptual design in structural and architectural engineering is necessary to achieve correct detailed design information of a building. The conceptual design in case2 determined project brief and examined the identification of feasible options. The general preferred design options are justified into conceptual design. The conceptual design report determined structural grid, structural zones, general shape and materials of frame and foundation, columns/beam locations, fire protection to the structure, sustainability analysis reports for producing CO_2, consumption of water and materials during the construction phase. The Case 2 project required efficient software to **facilitate conceptual design**, however, software that had been applied in case2 was well designed for obtaining detailed design but not for conceptual reports. For example interviewee SSE8 expressed as following:

"*…It's a very interesting question. We are looking at pieces of software to be fairly easy to go for a set of output in conceptual design. We got shapes and reports and it's difficult to write something that would give you the perfect model. Its degree of manual manipulation of input data and generate the model. It's very difficult to write something that you absolutely want it to do. So it is going to be manual manipulation there…*"

Finally, it was established by most of the interviewees in case2 that, the capability of software to access rich **product libraries** can dramatically promote information accessibility in their current design project. The interviewees in this case recommended to their IT department to enrich the ability of their software to synchronise products from online resources. They enrich libraries would cover variety of structural components in the choices of materials and sub-elements such as bolts, welding options, precast concrete etc.

In summary, four technology types were evaluated for their impact on information quality in this case study (Table 5-5). These included **visualisation, file format, semantic** and **software**. Visualisation had influence on accuracy, and comprised of three criteria *performance prediction, design optimisation, presenting critical zone and simplification*. Five out of the six participants held the view that performance prediction had a significant contribution towards information accuracy. Similarly, all participants felt that design optimisation influenced accuracy of information and another three of the six participants stressed that presenting critical zone and sizes affected accuracy of data. **File format** was an important consideration. It comprised of six criteria that affected different aspects of information quality. Of the six participants, four considered that information accessibility could be improved by *user notifications*; five felt that *simplifying access* would also help and another four interviewees held the view that *regular updates* of information would also contribute towards accessibility. Four out of the six interviewees were of the opinion that *third party secured access* would improve both security and accessibility. It was felt by four of the six participants that interoperability would be improved by having an *integrated search function*. In terms of accuracy and accessibility of information, five out of the six participants stated that information quality could be improved by addressing the issues that result from the use of *various terminologies* by the different disciplines involved in the project. In terms of **semantics**, accuracy and accessibility of information were the main concerns. Four out of the six participants felt that this could be improved by enabling a *key word search* and another four felt that having an *access to the meaning of the context* would also contribute. The use of appropriate **software** was a great concern. Five out of the six participants felt that accuracy was compromised due to the *lack of tools for early design*. Of the six participants, three were of the opinion that interoperability was affected by the open *version of the software* being used. Significantly, out of the six participants, four held the view that by using software to *facilitate conceptual design* information accuracy would all be improved.

Table 5-5 Technological BIM adoption in case 2

Technology type	**Criteria**	**Text percentage**	**Participants References**	**Influence on Quality**
	Performance prediction	1.7 %	5/6	Accuracy
	Design optimization	1.6%	6/6	Accuracy

Visualisation	Presenting critical zone	0.6%	3/6	Accuracy
	Simplification	0.6%	5/6	Accuracy
File Format	User notification	0.8%	4/6	Accuracy accessibility
	Simplify access	1.2%	5/6	accessibility
	Third party secured access	1.0%	4/6	Interoperability Security
	Integrated search function	0.9%	4/6	Interoperability
	Update data regularly	0.7%	4/6	accessibility Accuracy
	Covering Various terminologies	1.0%	4/6	Accuracy accessibility interoperability
Semantic	Keyword search	2.1%	4/6	Accuracy accessibility
	Access to meaning of	1.0%	5/6	Accuracy

	context			accessibility
Software	compatible Version	0.7	4/6	Interoperability
	Facilitate conceptual design	1.0	4/6	Accuracy

5.2.3.2 BIM Workflows Adoption in Case2

In the context of adopting BIM workflows, perception of the company in understanding BIM could have a critical role. It was believed by the interviewees in Case 2 that their organisation looks at BIM as tools and business services that can enable them to differentiate themselves from their peers. Overall, all the interviewees in case2 believed that improved structural models in terms of visualisation and improved document management system could distinguish the achievements of their company in the tough engineering and construction market in the UK.

Organisation B was at the stage of the BIM implementation process. It was indicated by majority of the interviewees that although a number of BIM workflows are available for application and there are many associations that discuss BIM related subjects another option would be to develop their own workflow for BIM implementation in Organisation B. It can be recommended by studying case2, that it is significant to contact with industry peers to obtain their opinion about implementing BIM workflows and frameworks that are available or efficient methods to develop their own workflows.

In terms of developing BIM workflows within a structural engineering company, Case 2 interviewees emphasised on the understanding of progressive BIM concepts and practices. Five out of six interviewees (SSE5, SSE6, SSE8, DM2 and BM2) expressed that novel BIM tools and BIM concepts need to be considered according to the requirements resulting from internal culture and budget in organisation B to develop an efficient process. It was felt by the vast majority of interviewees that even though their organisation was large in terms of turnover, size of projects and number of employees, a costly switch in technology could not be tolerated at both the management level and at the level of the users. Hence, it was imperative to consider the capability to change by both the management and the users while developing workflows to adopt new technologies.

The Case 2 study revealed that while planning for the adoption of BIM workflow to take into consideration the requirements of each phase of information management. The most critical criteria needed to be considered by their organisation prior to the adoption of BIM workflow in the structural engineering domain was indicated by the interviewees. As shown in Table 5-6, BIM workflows stages are categorised into *input*, *evaluation & documentation* and *publish* by interviewees. Case 2 interviewees were asked to specify the most critical criteria that should be considered during each stage of BIM workflow to enhance the information quality factors.

Table 5-6 BIM workflows adoption in case 2

BIM Workflow Stages	Criteria	Text percentage	Participants References	Influence on Quality
Input	Access to verbal contents (meetings, telephone conversation etc.)	1.4%	5/6	Accuracy Accessibility
	Clear document description	1.8%	4/6	Accuracy Accessibility
Evaluation & Documentation	Remote comments on documents	1.9%	4/6	Accuracy Accessibility Interoperability
	Document control system	1.8%	4/6	Accuracy Accessibiliy Interoperability Security

	Matching final information with client's requirements	1.9%	4/6	Accuracy
Publish	Access to technical contents	2.0%	5/6	Interoperability Accessibility
	Access to general contents	2.1%	5/6	Interoperability Accessibility

Capture of verbal information was considered as a controversial issue in Case 2. Five out of the six interviewees (SSE6, JSE7, SSE8, DM2 and BM2) believed that some significant requirements from client or architect are ordered during meetings or via telephone conversation and managing that information could aid in improving the quality of information in structural engineering firms. For example interviewee BM2 stated that:

> *"...in terms of meetings, when for example we have meetings to agree upon loading requirements, we formally capture the proceedings in a set of minutes, which records a text of the meeting and also of the sketches. This information would circulate afterwards as a type of capture, but, there is no efficient standard for managing the contents in the meetings and many times the information is messed up..."*

In the input stage, most of the interviewees emphasised on managing verbal information which is produced during meetings with the client and architects or via telephone conversation. They were of the opinion that in BIM workflow for information management in the structural engineering domain, it is very important to consider on developing standards or guidelines to show efficient ways of capturing and storing verbal information and it can affect information accuracy and information accessibility. For example interviewee SSE8 expressed regard to this point as follows;

> *"...We attend meetings conducted by architects with drawings. It's talking with the people. We had same issue in a recent project there was an issue in the drawing and*

he called me earlier and said it's a question. I said look, there is an issue on working progress file and he can change his drawing. Ideally we solve the issues before drawings..."

Clear document description was the second criteria recommended by the case2 interviewees in the adoption of BIM workflow. From Case 2, it is evident that although most of the interviewees claimed to know how to create file and document descriptions in the system, it is very important to take into consideration standards document description in BIM workflow. Four out of the six interviewees (SSE5, JSE7, SSE8 and BM2) were of this opinion that adopting a BIM workflow which described a standard way to show the right way of managing documents will affect accuracy and accessibility of information. In this regard interviewee DM2 pointed out that:

"...We have got fairly the way to file the information into system but not with QA (Quality Assurance) requirements. Maybe you have to file the information in certain places. For example when we have meetings with clients we have got files and folders in our system. So there should be definite standard in BIM workflow to get manager system and it could help us to create information precisely and more achievable..."

In the context of the evaluation and documentation stage of BIM workflow, four out of six interviewees (SSE5, SSE6, SSE8 and BM2) pointed out that remote comments on documents, document control system and matching final information with client's requirements are very critical points in adopting BIM workflow. These experts from Case 2 recommended describing interaction with external stakeholders in the evaluation and documentation stage of BIM workflow and controlling documents for revising those comments and changing contained information. They claimed that inclusion of standard methods of leaving comments on report information and drawing information, and systems for document control in the BIM workflow would help in maintaining the accuracy and accessibility of structural information. In this regard interviewee BM2 pointed out as follows:

"...Also there is a series of independent calculation tools and there is a series of calculations when you input the data you have got and do simple checks. It is very prescriptive so external users have raised concerns whether the calculation finds out the answer or is it suitable for the design. Sometimes external users need to leave us some feedback from different locations and we need to make sure changes have been

complied according their requirements and documents should be checked after any changes...". And interviewee SSE8 expressed that:

> *"...We have the system to capture sketches names and numbers and register of both, But also for internal sketches we can always go back to system and look at those to see how the design developed in that way. It's not perfect you can argue that something could be filed if you are talking to the architect or service engineer. It can get messy sometimes, but it's necessary to get filed, its maybe logical for you but it's not logical for somebody else..."*

The third criteria in evaluation and documentation stage of BIM workflow are matching the final information with client's requirements. Most of the interviewees held the view that although the client's expectations have been written in the contract; most of the requirements (for example loading requirements) were delivered from client to structural engineering department in Case 2 via dialogue. Structural engineering department received those requirements during the meetings. Four out of six interviewees (SSE5, SSE6, DM2 and BM2) pointed out that final outputs should be checked according to client's requirements and this process should be described in BIM workflow standard to reduce the errors of information. In this regard interviewee SSE6 stated as follows;

> *"...I guess for things like loading requirements in Arena we have been given the input as texts describing the requirements of the client, and further inputs are obtained from discussions in meetings and agreements and understanding. We capture and circulate on board to see Arena operators are happy. And we also have hand sketches and lots of drawings in PDF which circulate by meetings or by emails expressing what they want. There is mixture of information coming in perhaps most valuable information capture is from dialogue and hand scratches to receive that information and to just develop the understanding of information comes together..."*

The final stage of BIM workflow is identified as the publish stage. As pointed out by five out of six interviewees (SSE5, SSE6, JSE7, DM2 and BM2), client, local authorities, architecture and other design stakeholders need access to final design decisions. Calculations, drawings and reports should be monitored in evaluation stage and should be controlled in publish stage. It is evident from Case 2 project that in BIM workflow standard way of accessing into general and technical documents should be designed and it will affect positively on final interoperability with stakeholders. In this regard interviewee SSE5 pointed out as follows;

> *"...Most of our outputs are drawings. These circulate to the design team, client and potentially to the contractors. They are also shared with the authorities to make decisions on building control or planning and then the reports similarly circulate to design team and the client to monitor progress on the job and to capture design decisions to process and specifications are properly there for the contractors mostly and the architect in some aspect are interested and calculations are produced for building control..."*

5.2.3.3 Human Resources Readiness for BIM Adoption in Case 2

In this study, the assessment of Case 2 revealed certain issues related to human resource readiness in adopting BIM with impact on the quality of information. The first issue was related to *lack of skills* in using recent BIM tools and standards between both senior and junior structural engineers and the second one was the *lack of an efficient training strategy* to prepare structural engineers to adopt BIM tools. Most of the interviewees were of the opinion that their organisation specified job description merely based on creative technical and social abilities. Organisation B does not consider BIM skills as a strong influencing factor in their structural engineering recruitment system. And interviewees also indicated that in organisation B there are no efficient methods for imparting BIM training to the structural engineers after they have been hired.

Organisation B hired a BIM manager professional; however, most of the structural engineers in case2 believed that his duties and roles were not well defined. It was evident from interpretation of structural experts in Case 2 that, the BIM manager during Case 2 project acted as a BIM modeller consultant or CAD specialist. The BIM manager is expected to aid engineers to simulate their model in 3D and view 3D models that are transferred from other design disciplines. Therefore BIM manager during Case 2 project did not find enough time to research on BIM technological and workflows tools to increase information quality in structural engineering department in organisation B.

It was also evident from all interviewees that BIM cannot be adopted to improve information quality in their firm only by hiring BIM manager as this process is not individual work.

Interviewees in Case 2 recommended to list BIM software application skills, knowledge of BIM concepts and understanding of BIM standards into their job description for recruitment of senior structural engineers. It could influence on their communication, document management, virtual design models and building performance analysis and the accuracy, interoperability and accessibility of information will be improved.

Overall, most of the interviewees recommended BIM internship programmes for new junior structural engineers. The functional aspects of BIM technologies include drawing 3D model in detail, structural document management, Building performance analysis. Junior structural engineers can be trained in construction estimation costs, time and experience in adopting available BIM workflows in a short internship programme. For example interviewee SSE6 pointed out:

> *"...I suggest an internship programme, modelling structural elements, using related software capabilities for analysis, estimation and quantity take off can be trained in a classroom. And also BIM process standard which are already applied and their advantages and disadvantages can be offered..."*

Table 5-7 Human resources readiness BIM adoption in case 2

Human resource readiness strategy for implementing BIM	**Criteria**	**Text Percentage**	**Participants References**	**Influence on**
Recruitment structural engineers	BIM software application skill	0.3%	6/6	Accuracy Accessibility Interoperability
	Knowledge of BIM concepts	0.35%	6/6	Accuracy Accessibility Interoperability

	Understanding of BIM standards	0.4%	6/6	Accuracy Accessibility Interoperability
Training structural engineers	Conducting BIM internships	0.35%	6/6	Accuracy Accessibility Interoperability
	Defining role and responsibilities for BIM manager	0.25 %	4/6	Accuracy Accessibility Interoperability

According to Table 5-7, two major issues were identified related to human resource readiness to adopt BIM and these are **recruitment** and **training** of structural engineers. **Recruitment of structural engineers** was an important consideration that can positively impact on information accuracy, accessibility and interoperability. The interviewees held the opinion that BIM skills were not taken into consideration during the recruitment process. Three important criteria were proposed to address this issue and these were *BIM software application skills, knowledge of BIM concepts* and *understanding of BIM standards.* All the six participants held the unanimous view that during the recruitment of senior structural engineers, the job requirement should specifically include these three criteria. It was felt that **training of structural engineers** would also have a positive impact upon information accuracy, accessibility and interoperability. To address the issue of training, it was felt that two approaches may be used and these included *conducting BIM internships* and *defining the* *roles and responsibilities of the BIM manager*. All the six interviewees held that conducting BIM internships would greatly help junior structural engineers hone their skills in BIM technology. It was felt that training on the functional aspects of BIM technologies could be imparted in a short internship programme. Of the six participants, four held the view that defining the roles and responsibilities of the BIM manager would ensure systematic and focussed application of BIM technologies in the organisation. The BIM manger could provide guidance to structural engineers in simulating their models in 3D and also to interpret the 3D models created by other applications. Moreover, the BIM manager could then devote sufficient time in researching applicable BIM technologies and workflow tools that would eventually help in the improvement of information quality.

5.2.4 Case 2- Findings and discussion

Case 2 is a conceptual and detail of ongoing structural design of a multi-purpose arena project in organisation B. The key organisational success goals in Case 2 are outlined under building safety, health of people, sustainability, and design economy. Although in Case2 the organisation had access to efficient budget and resources for adopting novel information and communication technologies, the critical challenges in information management in Case2 were information quality dimensions. In the review of literature, (Section 2.2) it was indicated that that information interoperability, accessibility and accuracy are the key challenges in AEC industry and structural engineering discipline. As a result the findings from Case2 indicated that the key information management challenges faced include information accessibility, accuracy, interoperability, security and unstructured data.

Technological, workflows and human resources readiness are the domains of BIM that have been investigated in this research. The review of literature leads this research to categorised technological contribution of BIM to structural engineering under visualisation; file format & standards, semantic and software. It is revealed from Case2 that "performance prediction", "design Optimization", "presenting critical zone" and "simplification" are the key criteria that need to be considered while adopting efficient tools towards enhancing accuracy of information in the visualisation tier. The findings from Case 2 showed that the key criteria in adopting tools under file format and standards tier are: user notification, simplify access, third party secured access, integrated search function, updating data regularly and covering various terminologies. Majority of the participants held the view that by considering these criteria the level of information accessibility, accuracy and interoperability can be enhanced in their project (See section 5.2.3.1 for more details). Findings from Case 2 reveal that key word search and access to meaning of context are the key criteria that have to be considered while adopting semantic technologies towards enhancing accessibility and accuracy of information. In Case 2 investigation, the fourth BIM tier investigated was under the software context, and the findings indicated that the adoption of BIM based software can contribute towards accuracy, accessibility and interoperability of information in structural engineering. To enhance accuracy of information structural engineers are also recommended to consider compatible versions of software and to adopt structural engineering software that are facilitated to conceptual design capability.

In the BIM workflow adoption domain, literature review identified relevant BIM based workflows that are not specialised for structural engineering requirements (See section 3.3). The findings from Case 2 highlighted key criteria that are recommended to be considered by structural engineering organisations for adopting available workflow or create their own workflow to enhance information quality. The Case 2 shows that efficient workflow should be developed under three main information management processes; information input phase, evaluation & documentation phase and publish phase. The evidence from case1 indicates that access to verbal contents and clear document description (in information input phase), remote comments on documents, document control system and matching final information with client's requirements (in evaluation & documentation phase) and access to technical contents and access to general contexts (in publish phase) can dramatically contribute to information quality. The findings from Case 2 are emphasised on recruitment and training as two critical factors for adopting BIM. Literature review suggested internships and universities courses for making human resources ready for BIM adoption. The Case2 indicated BIM software applications skills, knowledge of BIM concepts and understanding BIM standards should be the main factors considered for recruitment of junior structural engineers. Also Case 2 findings indicate that conducting BIM internship and defining roles and responsibilities during training process of BIM for senior structural engineers can contribute to enhance information accessibility, information accuracy and information interoperability in structural engineering discipline.

5.3 Chapter Summary

This chapter discussed the key information management challenges in two different cases and the key criteria in adoption BIM towards developing a conceptual framework for enhancing information quality in structural engineering organisations in the UK. This chapter presents qualitative analysis of the data from semi-structured interviews with 12 structural engineers, design managers and BIM managers from two structural engineering departments embedded in two multi-disciplinary design and construction companies in the UK.

The qualitative findings show that information accuracy, information accessibility, information interoperability and information security are the most critical challenges in the both cases (current structural engineering projects). Except information security the other dimensions of information quality (accuracy, accessibility and interoperability) was identified as key challenges of information management in structural engineering sector in literature review (See Section 2.2). Moreover, this chapter investigates level of BIM adoption in both cases in three main BIM dimensions (Technology, workflow and human resources readiness). Although both cases are large company with large budget sources, they claimed that they are investing considerable in researches to aid them implement BIM, the maximum potential of technological, workflows and human readiness were not adopted in these cases. Both cases were at the planning stage of BIM implementation in their department and organisations and the interviewees had sufficient experience and knowledge to provide rich evidence refers to their current project in the context of structural engineering information management. Therefore, most critical criteria in adopting BIM in respect to contribution to information quality are examined through content data analysis (See table 5-2 to table 5-6). The critical criteria of adopting BIM in structural engineering organisations towards enhancing key dimensions of information quality are examined based on the number of interviews who emphasised on each particular criteria and percentage of transcribe text. The interviewees also rated the level of contribution of each criterion to information quality. The next chapter analysed quantitative data to support qualitative findings with larger sample and to measure the contribution of each identified criteria in adopting BIM to each key information quality dimensions (Accuracy, accessibility, interoperability and security).

CHAPTER 6. QUANTITATIVE DATA COLLECTION AND ANALYSIS

This questionnaire survey was conducted, subsequently to the interview. The extant study of literature with a qualitative analysis of interview on BIM adoption in two structural engineering projects in two different multi-disciplinary construction organisations in the UK, were combined to design questionnaire survey. The purpose of this questionnaire survey is to achieve wider perspective of the subject, generalise the challenges and solutions that interviewees argued and validate findings of research.

The state of the art on information management challenges and the potential power of BIM drivers for managing information was discussed and reviewed in chapters 2&3. It was followed by examining research methodology adoption in chapter 4. In chapter 5 the qualitative case study has been conducted to develop conceptual framework which shows the relationship between information challenges within large structural engineering department in multidisciplinary design and construction organisation in the UK. The analysis and findings of the questionnaire survey are presented in this chapter five sections based on the structure of the questionnaire survey (See Appendix E).The scope of the questionnaire focused in five sections as followings;

- Demographics of the survey sample
- Information challenges in the organisation
- BIM technological tools, workflows standards and human readiness strategies which are been using in structural engineering organisation
- Factor reduction (Factor analysis)
- Exploring relationships between independent and dependent variables (Multiple regression)

6.1 Demographics of survey sample

This chapter presents the quantitative analysis of data from questionnaire. Demographic data contributed to this research to present descriptive statistical study of population. Demographic data presents the characteristics of sample and on the other words, it provides summary about sample. The demographics data presents a clear view about experience of participants in structural engineering industry, their position in organisation, their organisation type, the size of organisation and also the most critical challenges and level of BIM usage in their organisations. This research requires data from structural engineering information system users, BIM experts who have experience in structural engineering sector and researchers who have knowledge in BIM adoption in structural engineering industry sector. Demographic data might provide general frequencies of participants in terms of their job role in organisation, their years of experience, and their organisation size and organisation type.

The result of this questionnaire is varied in terms of participant's years of experience. The highest representatives of participants have more than 15 years' experience in the UK structural engineering industry, which was 35.2% of overall sample and followed by 0-5 years of experiences (26.4%), 5-10 years of experience (22.4%) and 10-15 years of experience (16.0%) in the UK structural engineering industry. And they also have high education qualification in this filed. It can be seen on Figure 6-1, more than three quarter of participants in this questionnaire survey have more than 5 years' experience in structural engineering industry in the UK hence, it could emphasize the reliability of the data that this survey has collected.

Please specify the years of experience that you have got in structural engineering industry?		
Answer Options	Response Percent	Response Count
0-5 years	26.4%	33
5-10 years	22.4%	28
10-15 years	16.0%	20
more than 15 years	35.2%	44
	answered question	125
	skipped question	0

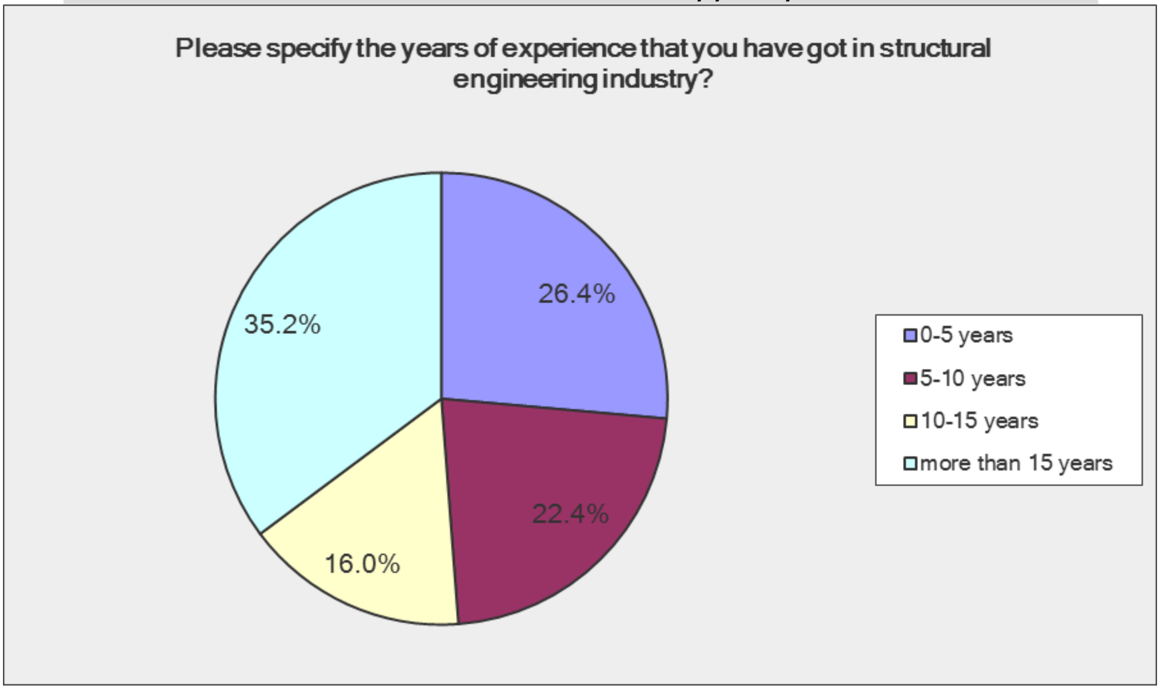


Figure 6-1 Participants Experience Percentage

The main structural information management users are targeted in this questionnaire. Junior structural engineers, senior structural engineers, BIM managers who are working with structural engineering information systems, design managers who are dealing with structural engineering information management and researchers who have knowledge about structural engineering information management in the UK were targeted as main participants in this questionnaire. Figure 6-2 presented participant’s current role in the UK construction industry. As shown in Figure 6-2 senior structural engineer were largest portion of total sample with 37.6%. The other organisational role personage of the total sample are presented in order as follows; BIM managers (21.6%), junior structural engineers (18.4%), Researchers (12.8%) and Design Managers (9.6%).

Please describe your current role in your organisation?		
Answer Options	**Response Percent**	**Response Count**
Junior Structural engineer	18.4%	23
senior structural engineer	37.6%	47
BIM manager	21.6%	27
Design manager	9.6%	12
Researcher	12.8%	16
Other (please specify)		
	answered question	125
	skipped question	0

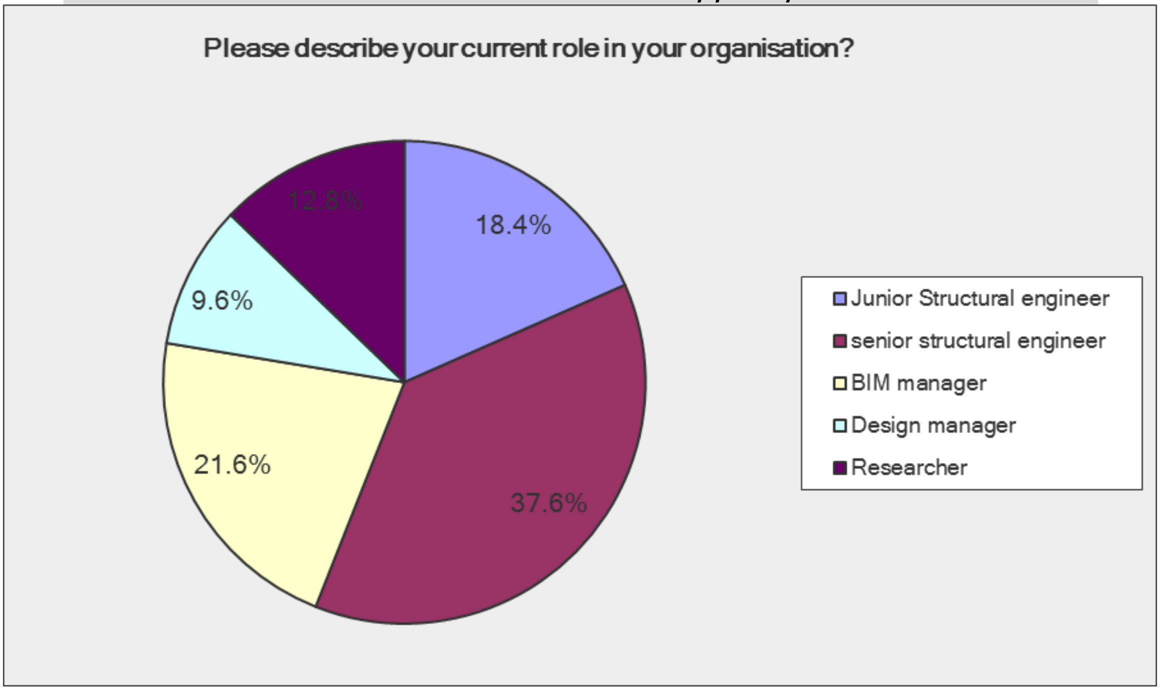


Figure 6-2 Participants Roles in Organisations

The second part of the demographic sample is related to organisation profile. In this part, this research seeks to identify the frequencies of organisations type and organisations size in the overall sample. Organisational type and size are an integral part of the quantitative survey analysis in this research. Due to this fact, and in the previous chapter (Qualitative case study analysis) this research focused on two cases which are structural departments in multi-disciplinary large organisation in the UK moreover, this chapter seeks to test is the most information management challenges that has been identified within large multi-disciplinary organisation can be generalised for other size and type of structural industry in UK or not. It would increase the level of validity of this research in achieving the first objective.

Please specify the type of your organisation?		
Answer Options	Response Percent	Response Count
Structural design	30.4%	38
Multidiciplinary enginnering consultany	38.4%	48
Architectural and engineering consultancy	8.8%	11
AEC multidisciplinary (design & construction)	22.4%	28
Other (please specify)		0
answered question		125
skipped question		0

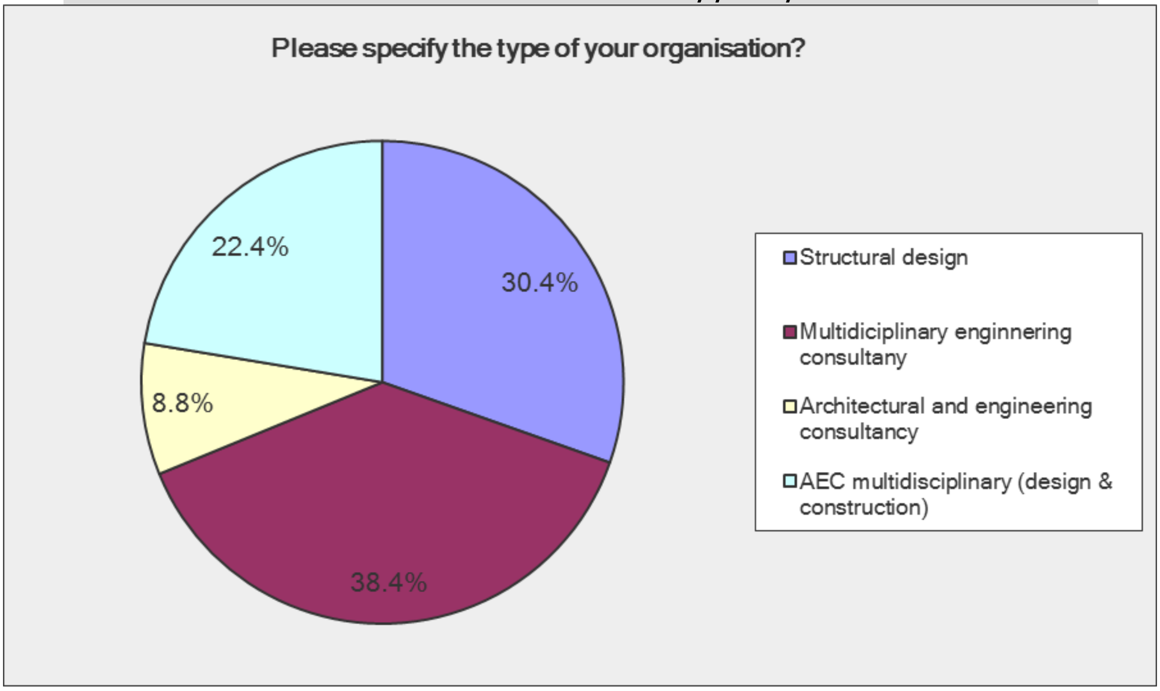


Figure 6-3 Participants' Types of Organsiations

The Figure 6-3 illustrated that out of total number of 125 participants, 38.4% of participants work in multidisciplinary engineering consultancy. Multidisciplinary engineering consultancy consist different engineering departments including; structural engineering department, mechanical engineering department and electrical engineering department. Those departments work together to provide full package of construction engineering design. The second group of participants in term of sample size work in structural engineering organisation with 30.4% of total sample size. Over 60% of the participants work in multidisciplinary companies. Therefore, this revealed that approximately 70% of participants have experience working with other department and integrated design to provide sufficient responses that can be reliable.

Please specify the size of your organisation		
Answer Options	**Response Percent**	**Response Count**
Small (Less than 50 employees)	40.0%	50
medium (between 50 to 100 employees)	25.6%	32
Large (more than 100 employees)	34.4%	43
	answered question	125
	skipped question	0

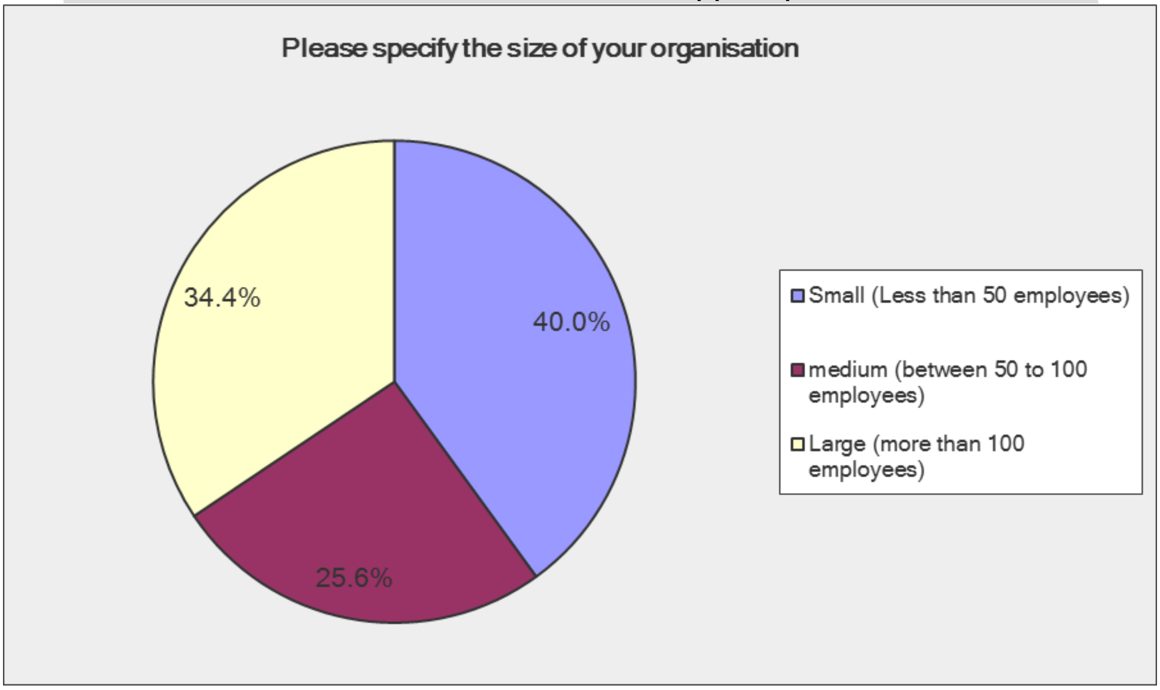


Figure 6-4 participants' size of organisations

This research categorised participants into three groups in terms of the size of their organisations which are small, medium and large size of organisations. Small size organisations are the organisations with less than 50 employees, medium organisation employed between 50 to 100 personnel and large organisations are considered with more than 100 employees (Kumar et al., 2001). It is shown from the Figure 6-4 that almost 65% of the participants come from small and medium size companies whilst 40% from small organisation and 25.6% from medium organisation. This distribution of participants helps this research this ability to use its findings to the benefit in terms of information management challenges and level of BIM adoption beyond merely large organisations. Moreover, the findings approximately cover all variety of organisations in terms of size and in the discussion chapter (Chapter 7) these results can be compared with the case study results which just covered two large multidisciplinary organisations. These comparisons of results from case study and quantitative survey will contribute to improvement of information quality management in structural engineering companies.

6.2 Information Challenges in the UK Structural Engineering Sector

The information management challenges in structural engineering domain are discussed in this section. This questionnaire survey listed a number of information management challenges in structural engineering sector. These challenges have been identified from the review of literature as presented in chapter two and analysis of the qualitative interviews presented in Chapter five. For each of these challenges, participants indicated their level of challenges by rating 1 to 5 point scale. Where 1 indicated “Not a challenge at all” and 5 indicated “Very Critical challenge”. The questionnaire adopted closed and open-ended design and participants can add other information challenges which they have faces in their company. The table 6-1 presented calculation of average rate of participants. The Weighted Score (WS) is calculated according to following equation:

Equation 7- Weighted Score Formula

$$WS = \sum_{n=1}^{5} \frac{nX}{125}$$

Where n = rating score, x = number of responses and 125 = total number of valid responses. Table 6-1 presents WS for each information challenges statement according to the number of responses among each ranking against the total number of participants. The WS more than 3 and close to 4 indicate that respondents tended to agree on the statement are critical challenge in their organisation. According to Table 6-1 information accuracy was the critical challenges in information management domain of respondent’s organisation by maximum weighted score (WS = 4.1). The respondents agree that information is not available in requested time in their organisation and second challenges can be interpreted as information availability (accessibility) in most of the respondent’s organisations (WS = 4.01). The Table 6-1 also shows that data exchange between different applications as sign of information interoperability in this research, which is third critical challenge in respondent’s organisation (WS = 3.59). Information security (WS = 3.49), missing verbal dialogue from meetings and telephone conversation (WS = 3.34) and Lack of information management standard (3.30) and tracking information (WS=3.19) are identified as critical information challenges in respect of respondent's organisations.

Table 6-1 Most Critical Information management challeneges

Please specify the most critical information management challenges in your organisation?							
Answer Options	Not a challenge at all	No challenge	Neutral	Critical challenge	Very critical challenge	Weighted Score	Response Count
Different format of data	22	21	38	29	15	2.92	125
Data exchange between different applications	20	15	14	38	41	3.59	125
Unavailable information in requested time	4	7	22	43	49	4.01	125
Lack of information management standard	14	18	33	37	23	3.30	125
Missing verbal dialogue information	14	35	33	35	19	3.34	125
Lack of internal communication	22	21	42	22	18	2.94	125
Lack of external communication	20	35	36	20	14	2.78	125
Information security	15	17	31	40	22	3.49	125
Tracking information	16	17	36	39	17	3.19	125
Information timeline	20	34	22	30	19	2.08	125
Information accuracy	6	7	9	38	65	4.1	125
Other (please specify)							2
						answered question	75
						skipped question	0

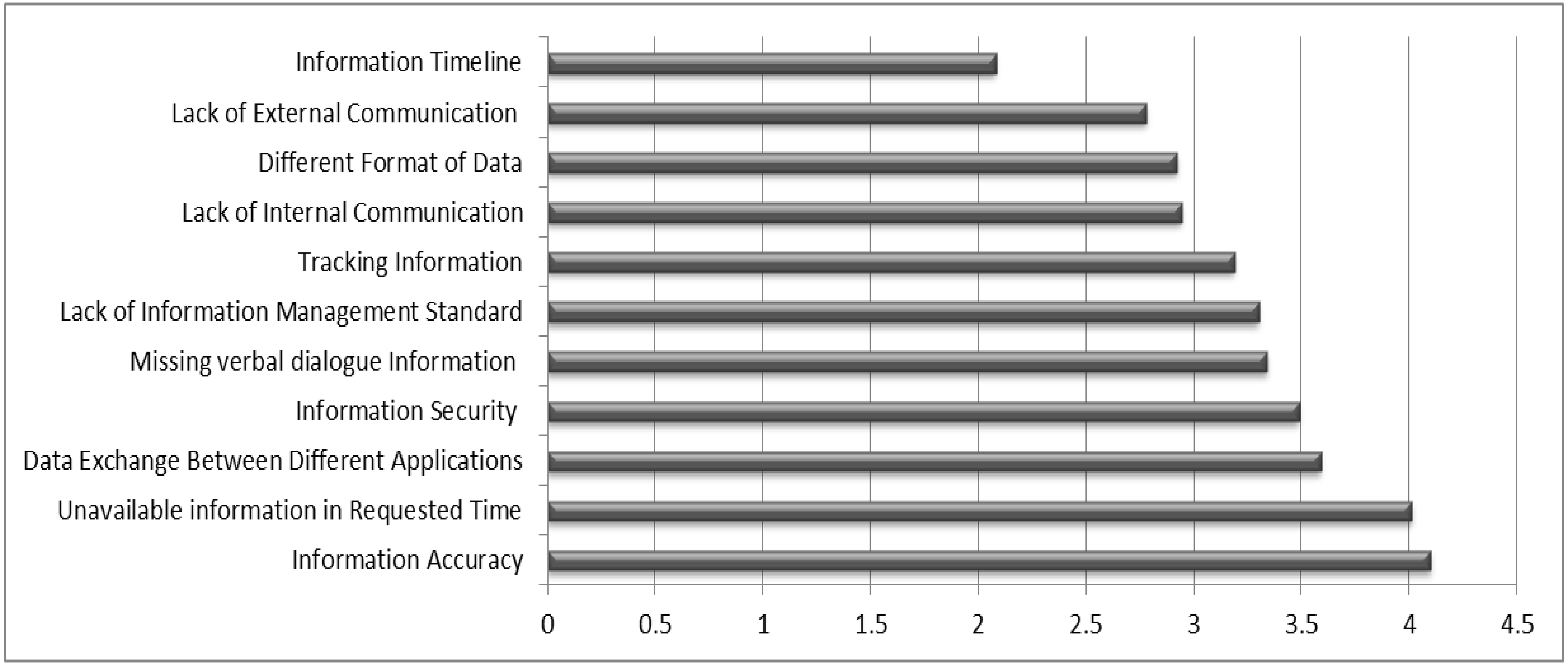


Figure 6-5 Most Critical Information management challenges

6.3 BIM Adoption in Structural Organisation in the UK

This survey investigated the respondents' perceptions of the BIM technological tools, available workflow in the UK and human resources readiness strategies which are used in their organisations. This group of questions firstly asked about technological tools which are categorised under four main tiers. Those tiers are identified in literature review and case study part of this research as visualisation, file format management, semantic and software.

The first group of technological tools in this questionnaire are categorised under visualisation. And those define how organisations develop their structural engineering model in terms of visualisation. The technological tools which are listed under visualisation tier are; 2D CAD drawing, 3D model, 4D model which also presented cost scheduling align with object geometry presentation, 5D model which also presented project time scheduling align with 4D model and virtual reality which presented a model with augmented reality. Virtual reality and augmented reality defined for the respondents that technologies facilitate engineer's highly photorealistic visualisation, rendering and animations.

2D drawing and 3D modelling were highest weighted scored options in visualisation tire (2D WS = 4.55, 3D WS = 3.96). It is indicate that respondents used 2D drawing very often and used 3D modelling often in their organisations. The respondents had neutral opinion about using 4D models, 5D models and virtual augmented reality visualisation, The WS ranged from 2.00 to 2.19. Therefore these models have been used sometimes in respondents companies.

There are currently a large number of file format and BIM open protocol such as Dwg, PDF, text file, Jpeg (image) file, spread sheet file, IFC, CIS2 and COBie available. Therefore, it is essential to determine types of file formats and BIM open protocol which are implemented in typical company practices. The survey result shows that Dwg, PDF and Text are the most use file format in the UK structural engineering industry. 68% of the respondents use Dwg file very often, 60% use PDF very often and 52% use text files very often. It can be seen also the WS ranged from 4.07 to 4.29. IFC, CIS2 and COBie information model are used rarely in the UK structural sector; the WS is ranged from 1.39 to 2.63. Additionally, IFC is used more than CIS2 and COBie in the UK structural domain. 22.7% of respondents use IFC data model very often and 9.3% of respondents use IFC often, However 64% of respondents do not use

CIS/2 data model and 76% of the respondents do not use COBie data model at all in their companies.

Table 6-2 shows the respondents level of semantic web usage to find specific context. In this regard, respondents have been asked to rate how often they use intelligent websites to find specific context. Over half of the respondents (56%) do not use semantic web at all or they use it rarely. 44% of the respondents rated that they do not use semantic web at all, and 12% of respondents agreed that they rarely use semantic web. The WS is ranged 2.60 and it can be interpreted that rate of semantic web between respondents in this survey is between rarely and sometimes.

This survey also showed that respondents mostly share their documents through cloud based platforms (e.g google drive, drop box and Microsoft drive) rather than sharing their documents through their web channel. The respondents indicated that cloud based platforms was utilised between sometimes and often range (WS = 3.24), however the utilisation of sharing documents through web channel was between rarely and sometimes (WS = 2.93) by their company.

The fourth tier of BIM technological aspect in structural engineering discipline is software adoption. Therefore, some available structural analysis and design packages which are developed based on BIM concepts are listed in questionnaire and respondents have been asked to rate how often they use those software packages in their organisations. Over half of the respondents (50.7%) do not develop their own analysis and design packages and they used available packages in the market. The Revit structural software is the most popular structural analysis and design package in the sample which is rated (WS= 3.08) and it is followed by the Tekla structure (WS=2.39) and Beantly structure (2.2).

Table 6-2 BIM Technologies tools utilisation weighted scores in questionnaire sample

How often in your organisation these following tools are used?							
Answer Options	Not at all %	Rarely%	Sometimes%	Often%	Very Often%	Weighted Score	Response Count
2D CAD drawing	1.3	4.0	6.7	14.7	73.3	4.55	125
3D model	2.7	9.3	26.7	12	49.3	3.96	125
4D model with cost scheduling	48.0	13.3	21.3	6.7	10.7	2.19	125
5D model with cost and time scheduling	56	10.7	10.7	5.3	17.3	2.17	125
Virtual reality (augmented reality)	61.3	4.0	14.7	13.3	6.7	2.00	125
IFC	40.0	12.0	16.0	9.3	22.7	2.63	125
CIS2	64.0	6.7	10.7	5.3	13.3	1.97	125
COBie	76.0	12.0	9.3	2.7	0.0	1.39	125
DWG file	5.3	5.3	12	9.3	68	4.29	125
PDF file	0.0	4.0	9.3	26.7	60.0	4.43	125
Text file	2.7	12.0	13.3	20.0	52.0	4.07	125
Spread sheet	0.0	4.0	20.0	22.7	53.3	4.25	125
JPEG file (Image file)	6.7	12.0	37.3	18.7	25.3	3.44	125
Tekla structure software	42.7	10.7	20.0	18.7	8.0	2.39	125
Revit structure Software	30.7	8.0	14.7	16.0	30.7	3.08	125
Beantly structure Software	61.3	2.7	12.0	2.7	21.3	2.20	125
Your own company software	50.7	6.7	9.3	5.3	28.0	2.53	125
Intelligent website for searching context (semantic web)	44.0	12.0	9.3	9.3	25.3	2.60	125
Sharing documents through web channel	30.7	14.7	16.0	8.0	30.7	2.93	125
Sharing documents through Cloud	25.3	5.3	18.7	21.3	29.3	3.24	125
answered question							125
skipped question							0

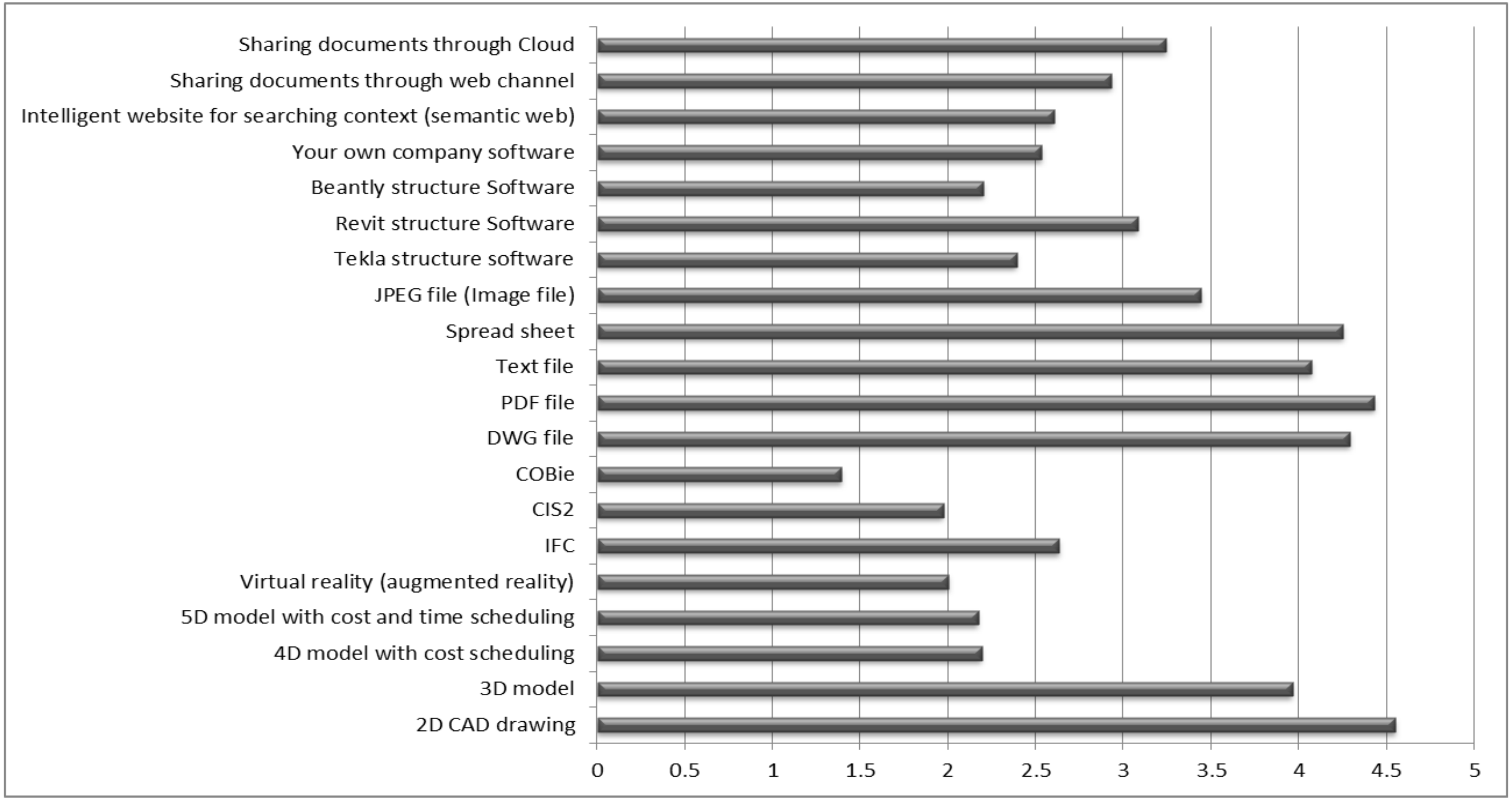


Figure 6-6 BIM Technological Tools Utilisation Bar Chart

The question in this part of the survey was intended to determine the predominant BIM workflow available for information management in the UK structural engineering industry. Those key available BIM workflows for implementing BIM in AEC industry are identified in literature review and case study part of this research as; PAS 1192-2, PAS 1192-3 and ISO 29481 (IDM). The respondents have been offered with two other options which are; they do not use any workflows for BIM implementation in their company, or other with specification.

Over 37.0% of respondents indicated that there is no BIM workflow has been used in their company. Figure 6-7 shows that 10.4% of the respondents rated other option. Those respondents mostly indicated that their company developed its own workflow for adopting BIM and for their information management procedure and some other parts argued that PAS1192-2 and PAS1192-3 should be implemented together.

What kind of information management standard has been using in your organisation? If you use your own standard please describe it in more		
Answer Options	Response Percent	Response Count
PAS 1192-2	22.4%	28
PAS 1192-3	20.8%	26
ISO 29481 (IDM)	9.6%	12
You do not use any BIM workflows	37.0%	46
Other (please specify)	10.4%	13
	answered question	125
	skipped question	0

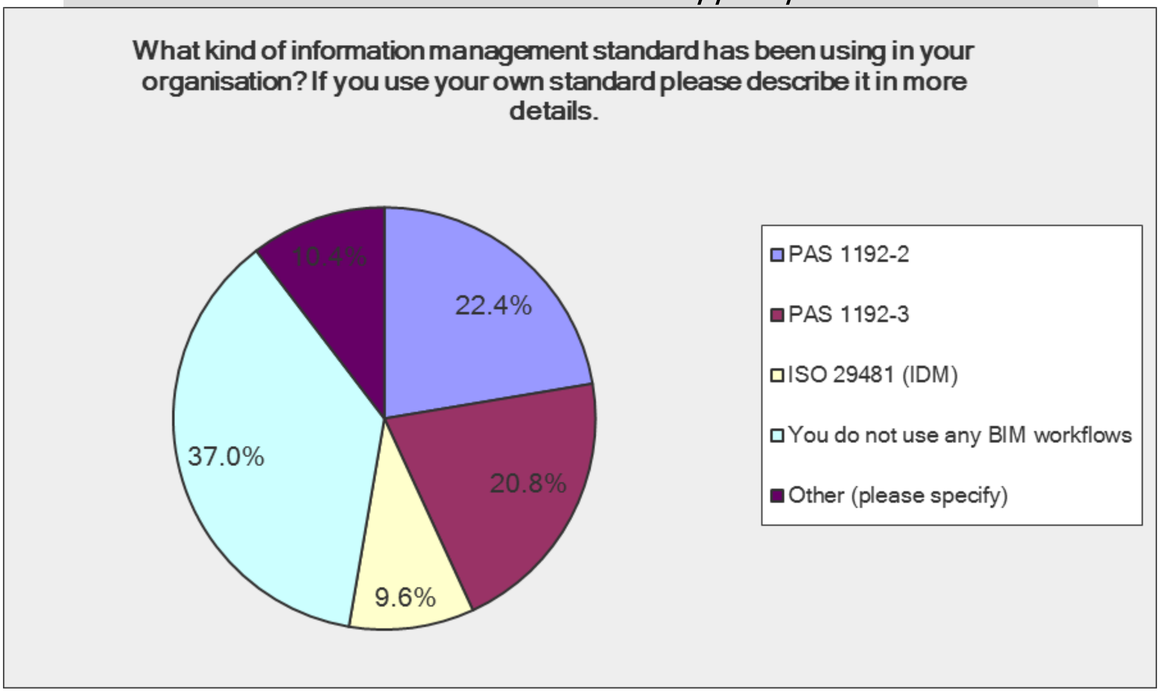


Figure 6-7 Information Management Standard Utilisation in the Sample

The objective of this chapter is to explore the relationship between BIM adoption and information quality dimensions in structural engineering organisations in the UK. The results from the case studies identified the key critical criteria of BIM implementation which can impact on different information quality dimensions (See Chapter 5). However, the results from the case studies present opinion from large size organisations with substantial capabilities and resources. This chapter intends to explore opinion from broader sample populations and from a variety of participants from different structural organisations characteristics and capabilities. The demographic data from survey sample shows that participants have sufficient years of experience in structural engineering discipline as junior structural engineers, senior structural engineers, design managers, BIM managers and researchers. Participant's rating can present the opinion of a variety of organisations in terms of size and types. Therefore, the results from case study and survey can be compared and discussed in greater detail to finalise clear understanding of structural engineering perceptions about the context.

The findings from section 6.2 presented information management challenges in the UK structural engineering sector and section 6.3 highlighted level of BIM adoption in the UK-based structural organisations. The findings from section 6.2 emphasised on key information quality dimensions just as the literature review. The findings indicate that information accuracy, unavailable information in requested time (related to information accessibility), data exchange between different applications (information interoperability) and information security are not only key challenges in large structural organisations (as highlighted in chapter 5) but also are the key challenges in small, medium and large structural organisations with a variety of types, capabilities and characteristics. This findings from survey so far also shows that structural engineering discipline in the UK have not used the potential benefits of BIM to address those challenges. The structural engineering industry has neither implemented novel BIM technology in the different identified tires, and nor have they adopted the available BIM workflows. This study assumed that by adopting maximum level of BIM potential in different domain (technology, workflows and human resources) the information quality will be enhanced substantially. The following sections in this chapter have measured the relationships between criteria of BIM adoption and information quality dimensions from results of the survey.

6.4 Factor Analysis

Exploratory factor analysis was employed for examining summarised structure within the set of measurement variables in the model. In the Factor analysis, thirty one variables have been entered into SPSS (Version 20.) and from which smaller set of factors or components were derived. According to Pallant (2010, p, 192), Kaiser-Meyer-Olkin of sampling adequacy (KMO) value is 0.6 or more and Bartlett's Test of Sphericity Significance less than 0.05 is shows that data set is suitable for factor analysis. In this case KMO value is 0.801 and Bartlett's Test of Sphericity significance is P = 0.000 (See Table 6-3).

Table 6-3 KMO and Bartlett's Test

KMO and Bartlett's Test	
Kaiser-Mater-Olkin of Sampling Adequacy	0.801
Bartlett's Sphericity Sig.	.000

To determine components that this research need to extract from variables set, there are some information from SPSS output which is needed to be considered. Firstly, Kaiser's criterion from running SPSS (Dimension Reduction Test) is considered. This research is interested only in components that have an Eigenvalue of 1 or more (Chen and Mohamed, 2007, Pallant, 2010). To determine how many factors meet this target, consideration has been taken into Total Variance Explained (See Table 6-4). The first six components recorded eigenvalues above 1 (12.065, 5.749, 3.804, 2.196, 1.094, 1.080). Those six components explain a total 83.83% of the variance.

Table 6-4 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.065	38.919	38.919	12.065	38.919	38.919
2	5.749	18.544	57.463	5.749	18.544	57.463
3	3.804	12.271	69.734	3.804	12.271	69.734
4	2.196	7.084	76.818	2.196	7.084	76.818
5	1.094	3.530	80.348	1.094	3.530	80.348
6	1.080	3.482	83.831	1.080	3.482	83.831
7	.796	2.567	86.398			
8	.623	2.009	88.406			
9	.552	1.781	90.188			
10	.456	1.472	91.660			
11	.345	1.112	92.772			

12	.326	1.052	93.823			
13	.229	.740	94.563			
14	.215	.693	95.256			
15	.200	.644	95.900			
16	.171	.552	96.452			
17	.159	.512	96.964			
18	.134	.432	97.397			
19	.120	.389	97.785			
20	.115	.371	98.156			
21	.113	.364	98.520			
22	.093	.299	98.818			
23	.070	.224	99.043			
24	.063	.202	99.244			
25	.056	.179	99.424			
26	.049	.160	99.583			

27	.039	.125	99.708			
28	.029	.093	99.801			
29	.025	.079	99.880			
30	.021	.068	99.948			
31	.016	.052	100.000			
Extraction Method: Principal Component Analysis.						

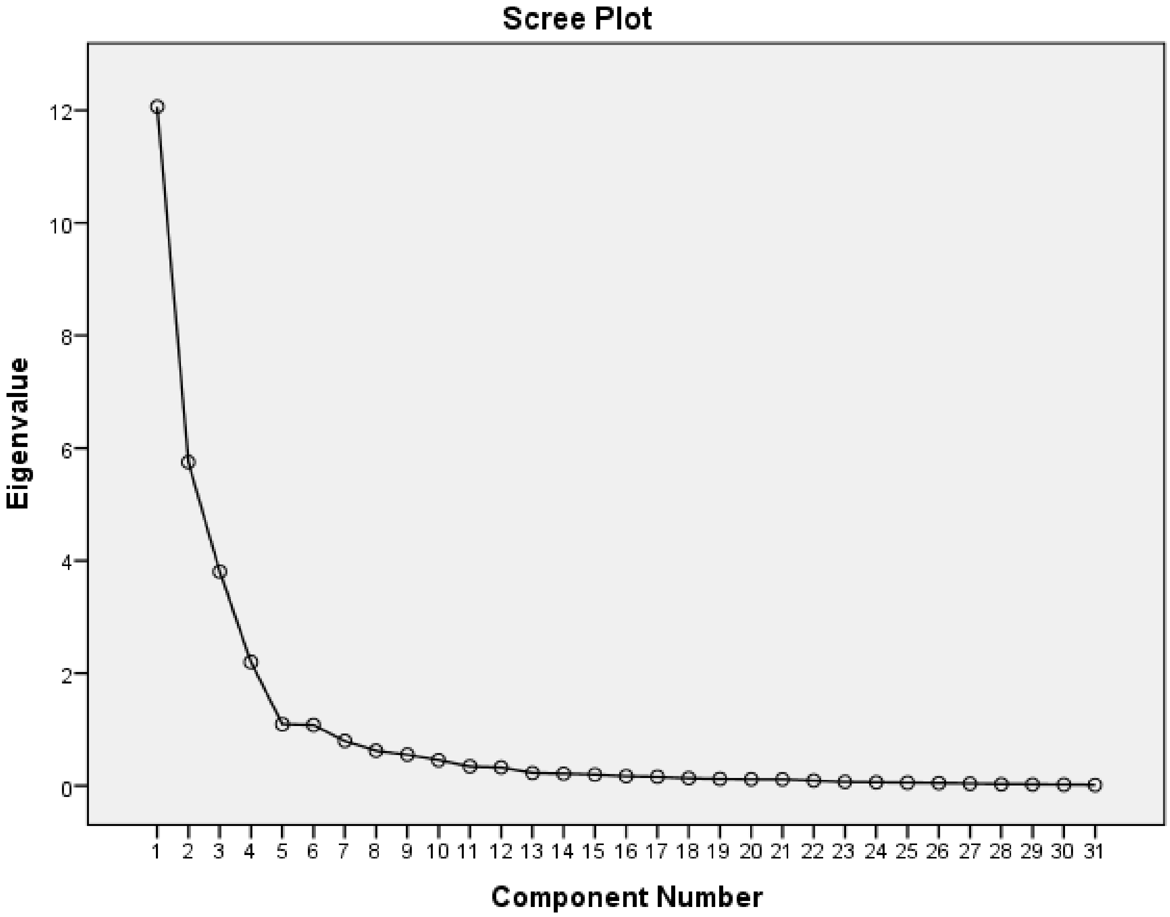


Figure 6-8 Scree Plot- Component Number

It is suggested by Pallant (2010, p, 192) to consider Scree plot for checking extracted components. The components above the change or elbow point in Scree plot are retained. As it can be seen in Figure 6-8, there is elbow point in sixth component. Hence based on eigenvalues (greater than 1.0) and interpretation of the Scree plots, the factor analysis identified six distinct factors. It can be seen in Table 6-5, most of the variables load reasonably (greater than 0.4) on first three components and very rare variables load on components 4, 5 & 6. It can be recommend three factors solution is likely to be more applicable.

Table 6-5 Component Matrix

Variables	**Components**					
	1	2	3	4	5	6
Access to general info at any time any where	.788			-.467		
BIM software application skills training	.783		-.423			
Information Accuracy	.779		-.450			
Contents of meetings acquisition	.766		-.432			
Capability of conceptual design	.726		-.556			
Access to meaning of context	.693			-.469		
Information Accessibility	.691	-.361	.522			
Knowledge of BIM	.689	-.358		.534		

concepts for Recruitment						
Information Updated regularly	.668	-.346	.500	-.345		
Integrated Search Function	.681					
Performance Prediction	.660		-.537			
Simplified Document Control System	.659	-.352	.457			
Access to Tech Info at any time any where	.643		-.613			
Remote control on comments	.643	.632				
Design Optimization					-.359	
Documents Descriptions	.633	-.392	.564			
Knowledge of BIM concepts Training		-.335	.380			
Final Documents and Clint’s Requirements Mapping	.608			-.493	.497	
User notification	.590		.516		-.406	
Information Security	.552					

Compatible Versions of Software	.444	.787				
Online collaboration capabilities	.571	.774				
Various terminologies Mapping	.526	.688				
BIM Software Application Skills for Recruitment	.425	.687				
Product Libraries contents		.686		.378		
Understanding of BIM Standards for Recruitment	.566	.666				
Understanding of BIM Standards Training	.618	.643				
Information Interoperability	.615	.641				
Third Party Secured Access	.503		-.625			.308
Keyword Search	.467	-.409	.496			.373
Model Simplification	.499			-.593		.451

The Factor analysis calculation repeated in procedure by SPSS (Version 20.) to run Oblimin rotation of three-factor solution. In second try Fixed Number of Factors option in Extraction button has been chosen. The number of fixed factors has given (3) as it has been discussed in the above paragraph, most of the variables loaded reasonably on the first three components. According to Table 6-6 three-factor solution explains about 70 % of the total variance, compared with 83% explained by the six factor solution.

Table 6-6 Total Variance Explained- Rotation of Three-factor Solution

Component	Initial Eigenvalues			Extraction Sums of Squared Loading			Rotation of Squared Loading
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	12.073	38.945	38.945	12.073	38.945	38.945	8.758
2	5.706	18.407	57.352	5.706	18.407	57.352	8.045
3	3.802	12.265	69.616	3.802	12.265	69.616*	9.156

The Oblimin rotation provided two tables of loadings; Pattern matrix and Structure matrix. The factors loading of each variable is illustrated in the Pattern matrix (See Table 6-7). In this research, the main loadings on component 1 are variables 1 to 13. The main variables on component 2 are 14 to 23 and the main variables which are loaded on component 3 are variables 23 to 33. The result in this research is a very clean output (Tabachnick and Fidell, 2007). Each of the variables loaded intensely on only one component and each component is signified by a number of strongly loading variables.

Table 6-7 Pattern Matrix

Variables		Components		
		1	2	3
1	Document Description	.971		
2	Information Accessibility Satisfaction	.948		
3	Information Updated regularly	.911		
4	Document Control System	.872		
5	User notification	.852		
6	Keyword Search	.842		
7 8	Knowledge of BIM concepts Training	.783		
9	Knowledge of BIM concepts for Recruitment	.510		
10	Access to General Info at any time any where	.443		
11	Final Documents and Clint's Requirements Control	.417		
12	Access to meaning of context	.398		
13	Information Security	.388		

	Satisfaction			
14	Online collaboration capabilities		.964	
15	Versions of Software Mapping		.931	
16	Various terminologies Mapping		.878	
17	Remote control on comments		.876	
18 19	Understanding of BIM Standards for Recruitment		.859	
20	Understanding of BIM Standards Training		.852	
21	Information Interoperability		.850	
22	BIM Software Application Skills for Recruitment		.806	
23	Product Libraries contents		.783	
24	Access to Tech Info at any time any where			.966
25	Third Party Secured Access			.930
26	Performance Prediction			.909

27	Capability for Conceptual Design			.907
28	Information Accuracy Satisfaction			.889
29	Contents of Meetings retrieval			.885
30	BIM Software Application Skills Training			.851
31	Integrated Search Function			.523
32	Design Optimization			.404
33	Model Simplification			.344

To sum up, 33 variables were subjected to principal components analysis using SPSS version 20. Prior to principal component analysis the suitability of data for factor analysis was assessed. The Kaiser-Meyer-Olkin value was 0.801, exceeding the suggested value of 0.6 (Kaiser, 1974). And Bartlett's Test of Sphericity reached statistical significance, supporting the factorability of the correlation matrix.

The principal components analysis has revealed the presence of six components with eigenvalues exceeding 1, explaining 38.92%, 57.47%, 69.73%, 76.82%, 80.34% and 83.83% of the variance respectively. An inspection of the Screeplot revealed a clear break after the sixth component. The three-component solution explained a total 69.62% of the variance, with component 1 contributing 38.94%, component 2 contributing 18.41% and component 3 contributing 12.27%. To aid in the interpretation of those three components, Oblimin rotation was performed.

Three components showed a number of strong loadings of variables. The variables (Document description, **information accessibility satisfaction**, information updated regularly, document control system, user notification, keyword search, knowledge of BIM concepts training, knowledge of BIM concepts in recruitment, access to general information at any time anywhere, final documents and client's recruitment control, access to meaning of context and **information security satisfaction**) are loaded with positive effects on component 1. Variables (Online collaboration capabilities, versions of software mapping, various terminologies mapping, remote control on comments, understanding of BIM standards for recruitment, understanding of BIM standards training, **information interoperability satisfaction**, BIM software application skills for recruitment, Product Libraries contents) are loaded strongly on component2. And variables (Third Party Secured Access, performance prediction capability for conceptual design, **information accuracy satisfaction**, contents of meetings retrieval, BIM software application skills training, integrated search function, design optimization and model simplification) are loaded strongly on component 3.

6.5 Multiple Regression Analysis

This part of quantitative data analysis addresses the third objective of this research which is asked; to examine the relationship between identified key challenges within structural information management and BIM technologies, processes and human resource readiness dimensions. The first part of this section is interested to examine the correlation between BIM domain Options including options in BIM technology domain, BIM workflows domain, and BIM human resource readiness domain in structural engineering organisations and criteria which have been examined in case study which should be taken into consideration for increasing the level of information quality in structural engineering industry.

Respondents were asked to rate all technological, workflows and human resource readiness criteria for BIM implementation in their company, according to five points Likert scale. In question 11 to 13 respondents requested to describe how satisfy they are about those criteria. And in question 14 respondents requested to rate how they are satisfy about four main information quality dimensions (Information Accuracy, Information Interoperability, Information accessibility and Information Security). Hence, multiple regressions applied in this research to test which dependent variables in BIM contributions could contributes to the predictive ability of the framework.

Multiple regressions are a family of techniques that can be employed to examine the relationship between number of independent variables (Predictors) and one dependent variable. Multiple regression is relies on correlation, however, this method enables more explorations within a set of variables (Pallant, 2010, p 148). The key criteria for adopting each BIM dimensions (technology, workflows and human readiness) are identified in literature review and case study in this research. Those key criteria are independent variables which can predict information quality outcomes (information accuracy, information accessibility, information interoperability and information security). Therefore, multiple regressions has been used in this research to measure contribution of each key criteria in BIM implementation in structural engineering information management to predict level of each information quality dimensions.

In previous section (Section 6-4) Factor analysis aid this research to categorise its variables into three main components. Components 1 provided a set of independents variables and two dependent variables (information accessibility satisfaction & information security satisfaction). Component 2 provided a set of independent variables and one dependent variable (information interoperability satisfaction). And component3 provided a set of variables and information accuracy as a dependent variable. These specific dependent variables were hypothesised as being influenced by specific set of independent variables (See Figure 6-9). The multiple regression would support this claim, that specific predictors in each components explains reasonably.

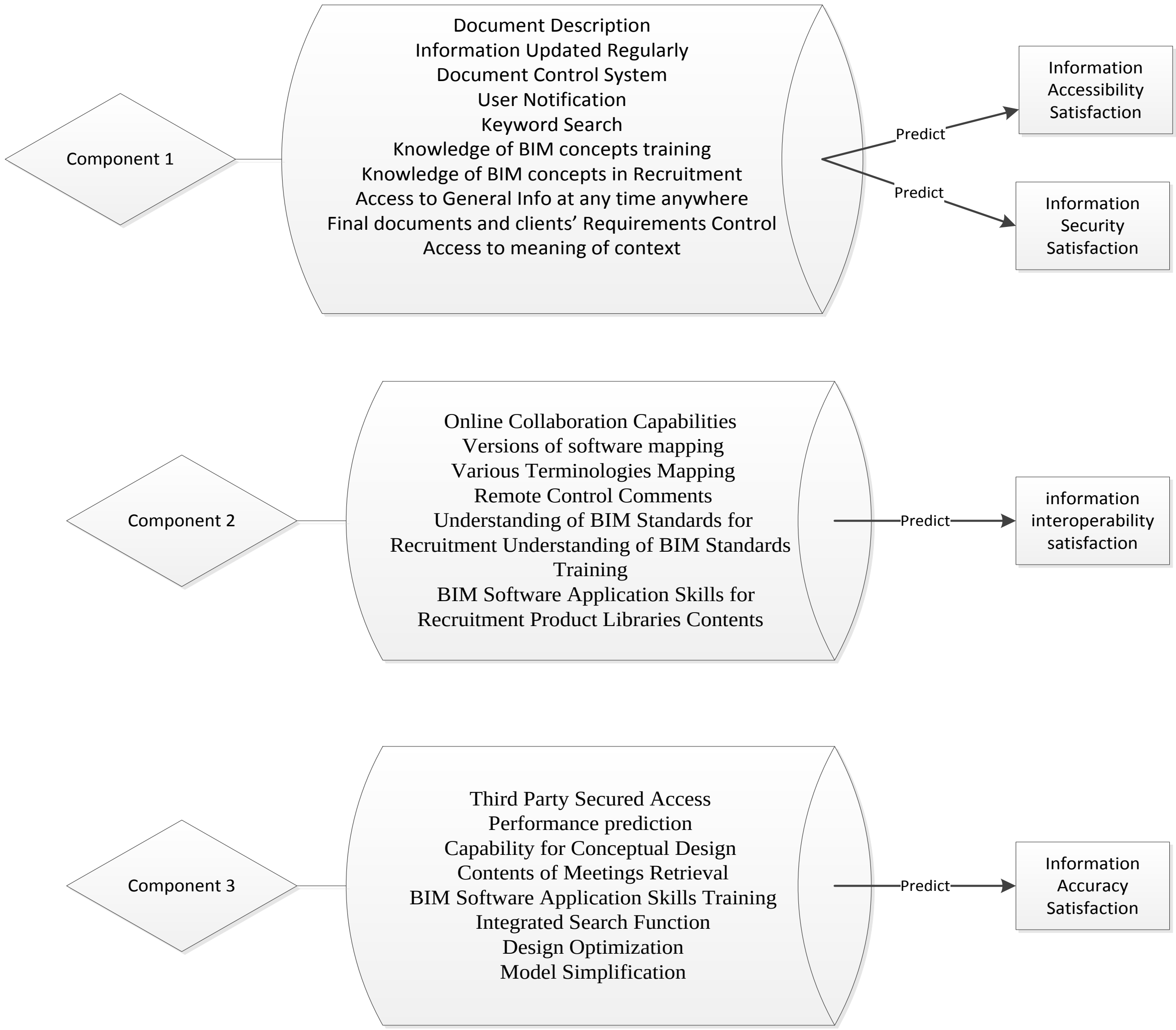


Figure 6-9 Components, independents variables and dependent variables

The major assumptions for multiple regressions are explained in section 4.7.4.2 of this thesis. The main assumptions have been checked in earlier part of the multiple regression analysis. The questions that multiple regressions analysis is answered in this research are; 1- How well identified BIM implementation criteria in technology, workflows and human readiness predict satisfaction of accuracy, accessibility, interoperability and security of structural information? 2- Which are best predictors to develop a framework? To explore these questions, this research employed standard multiple regression to measure how much variance of each independent variables explains in independent variable. The first assumption in multiple regressions is checking the normality distribution of data. Section 6.5.1 below investigated normal distribution of data in this survey.

6.5.1 Assessing Normality

At this section the normality of the four main dependent of variables are checked. At this section the frequency of those variables are examined to check if the scores are distributed in middle with smaller frequencies towards extreme or not. Table 6-8 presents descriptive statistic which refers to four targeting dependent variables in this research. One of the statistic parameter in this table is 5% trimmed mean. SPSS eliminated 5% of top and bottom of the cases and the new mean is calculated. It can be investigated that those two means are different and further investigation would be required to check the normality.

In addition the below Table 6-8 represents results for Skewness and Kurtosis parameters. The statistic measure and standard error are presented for both Skewness and Kurtosis. The skewness and Kurtosis measures should be as close to zero. In reality often data are skewed and kurtosis. According to Doane and Seward (2011) the measures should be divided by its standard therefore the Z-value is given which should be somewhere between -1.96 to +1.96 (Doane and Seward, 2011). Therefore for information accuracy Z-value for Skewness is 0.226/0.277 = 0.81 which is between -1.96 and +1.96. And Z-value for Kurtosis is -1.230/0.548 = 2.24 which is not between -1.96 and +1.96 therefore it cannot be concluded that data are normal distributed only by referencing on this test and it needs to investigate in further point.

Table 6-8 Results of Skewness and Kurtosis parameters

Information Quality Satisfaction	**Statistic**	**Std. Error**
Mean	11.6933	0.58107
95% Confidence Interval for Mean Lower Bound	10.5355	
95% Confidence Interval for Mean Upper Bound	12.8512	
5% Trimmed Mean	11.6593	
Median	12.000	

Variance	25.324	
Std. Deviation	5.0322	
Minimum	4.00	
Maximum	20.00	
Range	16.00	
Interquartile Range	9.00	
Skewness	0.201	0.277
Kurtosis	-1.183	0.548

The Table 6-9 presents results of Kolmogorov-Smirnov statistic. This test assesses the normality of data (Lehmann, 2006). According to Pallant (2010) when significant Value (Sig.) is more than 0.05 that could be accomplished normal distribution of data. In this research the Significant Value of all four dependent variable (Information accuracy, Information accessibility, Information interoperability and Information security) are 0.000 meaning normal distribution cannot be concluded from this result.

Table 6-9 Results of Kolmogorov-Smirnov Statistics

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	df	Sig.	Statistic	df	Sig.
Information Quality Satisfaction	0.115	75	0.015	0.936	75	0.001

In the course of checking normality of dependent variables, this research determined Information Quality Satisfaction as a variable which explains average distribution of all the four dependent variables (Information accuracy satisfaction, information accessibility satisfaction, information interoperability satisfaction and information security satisfaction). The definite shape of the distribution for variables can be seen in the below histogram Figure 6-11 (e.g. information accuracy). In this example distribution it appears to be normally distributed. It can be obtained also from Q-Q plot (Figure 6-10) which represents value for scores alongside value from the normal distribution. In this example, the below histogram Figure 6-11 shows approximate shape of a normal curve. In addition normal Figure 6-10 shows all dots are distributed aligned the line and box plots approximately is symmetrical.

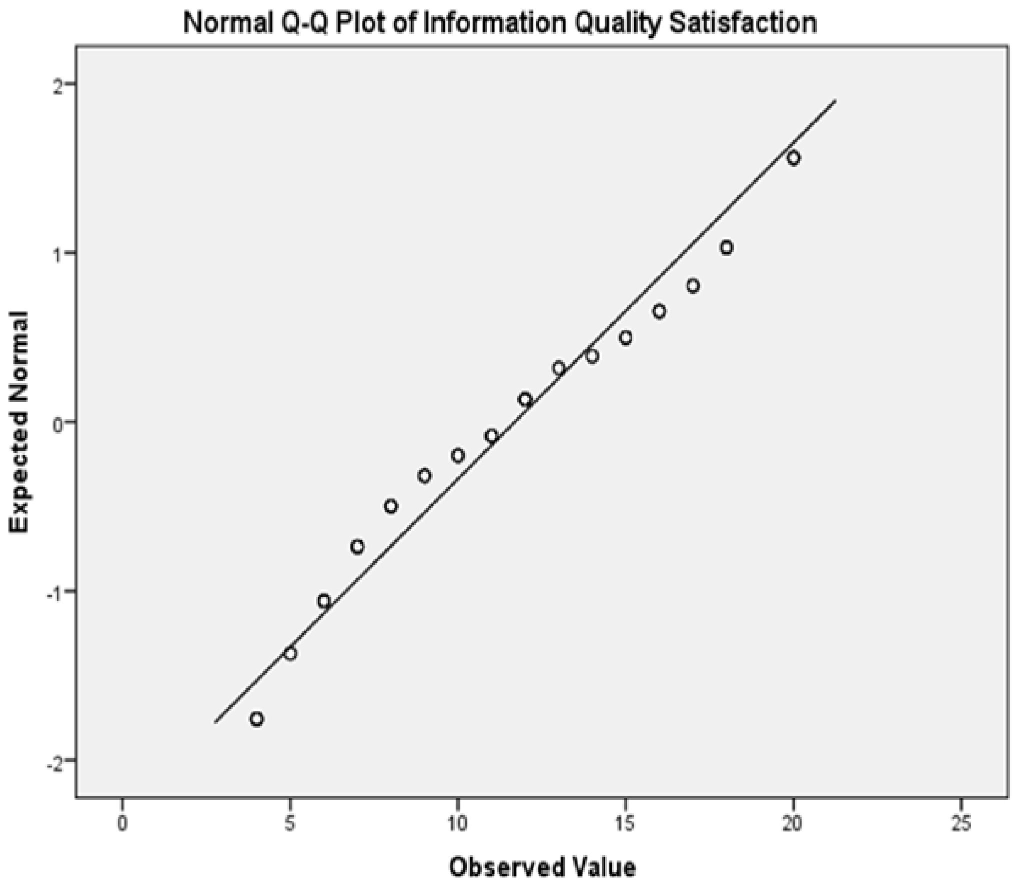


Figure 6-10 Plot of Information Quality Satisfaction

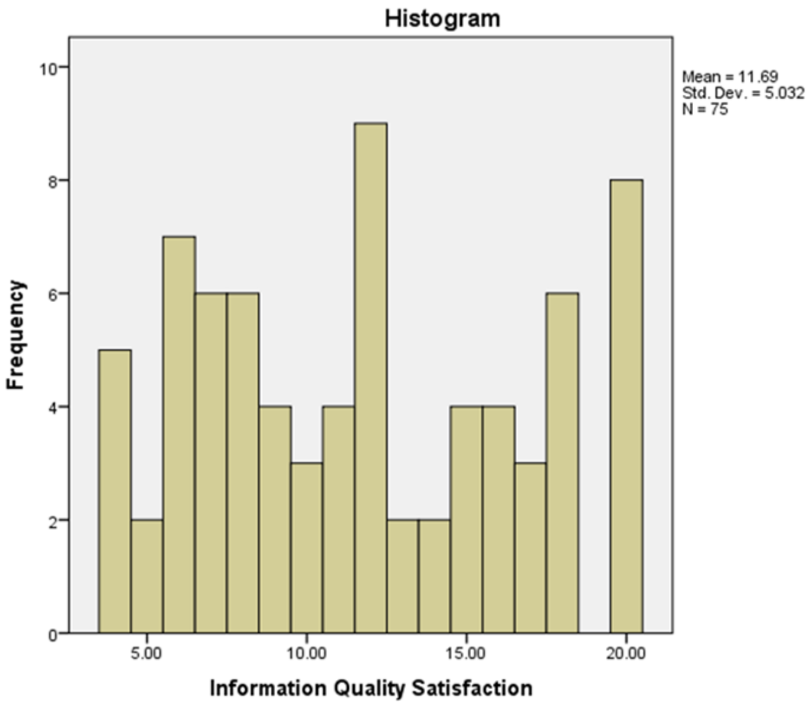


Figure 6-11 Histogram of Information Quality Satisfaction

6.5.2 Interpretation of Multiple Regression Output

The standard multiple regression has addressed this question. How well independents variables in each three components predict related dependent variables? The results will indicate how well those set of variables are able to predict each information quality dimension satisfaction. This involves independent variables in component 1 being entered in the model at once with information accessibility satisfaction and at once with information security satisfaction. Independent variables in component 2 are being entered into model at once with information interoperability satisfactory and independents variable in components 3 entered to predict information accuracy satisfaction (See Figure 6-8).

The correlations between independent and dependent variables are presented in Table 6-9. This research considered only independent variables which show above 0.3 correlations with dependent variables. According to Table 6-9, there was a strong and positive correlation between independent variables under component 1 and information accessibility satisfaction. It can be seen in the Table 6-10 that there was strong and positive correlation between variables in component 1 and information security satisfaction; however, the values are less than correlations between variables under component 1 and information accessibility satisfaction. Therefore all independent variables under component 1 which correlated with information accessibility will be retained. Expect two independent variables (User Notifications & Knowledge of BIM concepts for Recruitment) which influencing on information security, all independent variables in component 1 will be retained for further investigations. Table 6-10 shows that there are strong and positive correlations between independents variables under component 2 and information interoperability satisfaction (above 0.3) therefore all independent variables under component 2 will be retained for next investigation. It can be seen also seen that almost all independent variables under component 3 have strong and positive correlation with information accuracy satisfaction except (Model Simplification) which is less than 0.3.

Table 6-10 Correlation Matrix

	Information Accessibility Satisfaction	Information Security Satisfaction	Information Interoperability Satisfaction	Information Accuracy Satisfaction
Document Description	0.849	0.471	Not Entered	Not Entered
Information Updated regularly	0.826	0.369	Not Entered	Not Entered
Document Control System	0.780	0.406	Not Entered	Not Entered
User notification	0.727	0.265<0.3	Not Entered	Not Entered
Keyword Search	0.737	0.264<0.3	Not Entered	Not Entered
Knowledge of BIM concepts Training	0.816	0.404	Not Entered	Not Entered
Knowledge of BIM concepts for Recruitment	0.660	0.277<0.3	Not Entered	Not Entered
Access to General Info at any time any where	0.552	0.519	Not Entered	Not Entered
Final Documents and Clint's Requirements Control	0.478	0.429	Not Entered	Not Entered

Access to meaning of context	0.499	0.425	Not Entered	Not Entered
Online collaboration capabilities	Not Entered	Not Entered	0.804	Not Entered
Versions of Software Mapping	Not Entered	Not Entered	0.717	Not Entered
Various terminologies Mapping	Not Entered	Not Entered	0.742	Not Entered
Remote control on comments	Not Entered	Not Entered	0.802	Not Entered
Understanding of BIM Standards for Recruitment	Not Entered	Not Entered	0.755	Not Entered
Understanding of BIM Standards Training	Not Entered	Not Entered	0.793	Not Entered
BIM Software Application Skills for Recruitment	Not Entered	Not Entered	0.594	Not Entered
Product Libraries contents	Not Entered	Not Entered	0.593	Not Entered
Access to Tech Info at any time any where	Not Entered	Not Entered	Not Entered	0.836

Third Party Secured Access	Not Entered	Not Entered	Not Entered	0.722
Performance Prediction	Not Entered	Not Entered	Not Entered	0.749
Capability for Conceptual Design	Not Entered	Not Entered	Not Entered	0.820
Contents of Meetings retrieval	Not Entered	Not Entered	Not Entered	0.883
BIM Software Application Skills Training	Not Entered	Not Entered	Not Entered	0.917
Integrated Search Function	Not Entered	Not Entered	Not Entered	0.559
Design Optimization	Not Entered	Not Entered	Not Entered	0.452

The next factor that is suggested to be checked in multiple regression by Pallant (2010, P, 161) of the variables included in the model contributed to the prediction of dependent variables is coefficients. This research is interested in comparing the contribution of each independent variable those that are listed under three different components. It can be looked down the Beta column and find which values are the largest regardless of negative signs. In addition to each of those variables, it has been suggested to check column marked significant (Sig). This value can illustrate whether that specific variables is providing a statistically significant contribution to the model or not. It is much related to how much overlap is existing within independent variables. In this research if Significant Value is less than 0.5 (Tabachnick and Fidell, 2007), that independent variables will be providing a significant contribution to the prediction of the related dependent variables.

In this research standard multiple regression analysis examines key predictors in each component of variables which can explain information quality dimensions in structural information management. Table 6-11 indicated that independent variables; *Simplified document control system* (Beta = 0.202, Sig = 0.004), *knowledge of BIM concepts training* (Beta = 0.342, Sig = 0.004) and *access to meaning of context* (Beta = 0.102, Sig = 0.000) have large Beta values and in addition they significantly contributed to the information accessibility satisfaction due to Significant Value are less than 0.005. In can be seen in Table 6-11, that no independent variables; will be significantly contributed to predict information security satisfaction due to the fact that none of these variables have Significant Value less than 0.005.

The results in the Table 6-12 indicate that five independent variables; *online collaboration capabilities* (Beta = 0.396, Sig = 0.003), *various terminologies mapping* (Beta = -0.139, Sig = 0.003), *Remote control on comments* (Beta = 0.340, Sig = 0.04), *understanding of BIM standards for recruitment* (Beta = 0.277, Sig = 0.003) and *BIM software application skills for recruitment* (Beta = -0.188, Sig = 0.001) have large Beta values and in addition they significantly contributed to the information interoperability satisfaction equation due to the fact that Significant Value are less than 0.005. It can be seen in Table 6-13, four independent variables; *performance prediction* (Beta = -0.220, Sig = 0.003), *contents of meetings retrieval* (Beta = 0.377, Sig = 0.000), *BIM software application skills training* (Beta = 5.803, Sig = 0.000) and *design optimization* (Beta = 1.220, Sig = 0.02) *will* be significantly contributed in an equation to predict information accuracy satisfaction due to large Beta value and having Significant Value less than 0.005 in parallel.

Table 6-11 Regression Model for Information Accessibility

Model (Information Accessibility)	Standardised Coefficients Beta	Sig.
(Constant)		0.005
Document Description	0.202	0.067
Information Updated regularly	0.119	0.333
*Simplified Document Control System	0.160	0.04
User notification	0.063	0.003
Keyword Search	0.232	0.07
*Knowledge of BIM concepts Training	0.343	0.000
Knowledge of BIM concepts for Recruitment	0.067	0.339
Access to General Info at any time any where	0.163	0.151
Final Documents and Clint's Requirements Control	-0.004	0.961
*Access to meaning of context	0.102	0.000

Table 6-12 Regression Model for Information Security

Model (Information Security)	Standardised Coefficients	Sig.
	Beta	
(Constant)		0.000
Document Description	0.328	0.136
Information Updated regularly	-0.131	0.539
Document Control System	0.011	0.958
Knowledge of BIM concepts Training	0.099	0.527
Final Documents and Clint's Requirements Control	0.143	0.331
Access to meaning of context	0.234	0.096

Table 6-13 Regression Model for Information Interoperability

Model (Information interoperability)	Standardised Coefficients	Sig.
	Beta	
(Constant**)**		0.005
Online collaboration capabilities	0.396	0.03
Versions of Software Mapping	-0.104	0.502
*Various terminologies Mapping	0.139	0.003
*Remote control on comments	0.340	0.004
*Understanding of BIM Standards for Recruitment	0.277	0.003
Understanding of BIM Standards Training	0.185	0.183
*BIM Software Application Skills for Recruitment	0.188	0.001
Product Libraries contents	0.154	0.151

Table 6-14 Regression Model for Information Accuracy

Model (Information Accuracy)	Standardised Coefficients	Sig.
	Beta	
(Constant**)**		
Access to Tech Info at any time any where		
Third Party Secured Access	0.181	0.013
*Performance Prediction	0.220	<u>0.003</u>
Capability for Conceptual Design	0.164	0.046
*Contents of Meetings retrieval	0.377	<u>0.000</u>
*BIM Software Application Skills Training	5.803	<u>0.000</u>
Integrated Search Function	0.040	0.502
*Design Optimization	1.220	<u>0.002</u>
Model Simplification	-0.096	0.019

6.5.3 Evaluating Multiple Regression Model

Table 6-15 shows percentage of variance for the criteria that can be accounted for by predictors. As R Square presented in Table 6-15 86.5 % of the variance in information accessibility satisfaction, 31.1 % of the variance in information security satisfaction, 75.2 % of the information interoperability satisfaction and 90.3 % of information accuracy satisfaction in structural engineering domain can be accounted for by Predictors.

Table 6-15 Multiple Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Information Accessibility	0.930	0.865	0.843	0.646
Information Security	0.558	0.311	0.250	0.978
Information Interoperability	0.867	0.752	0.722	0.822
Information Accuracy	0.950	0.903	0.889	0.543

The Normal probability (P-P) plot and scatter plots of the regression standardised analysis is presented in Figure 6-12. In Normal P-P plot for each model the points are laid in a reasonably diagonal line from bottom left to top right. That could recommend any major violate from normality.

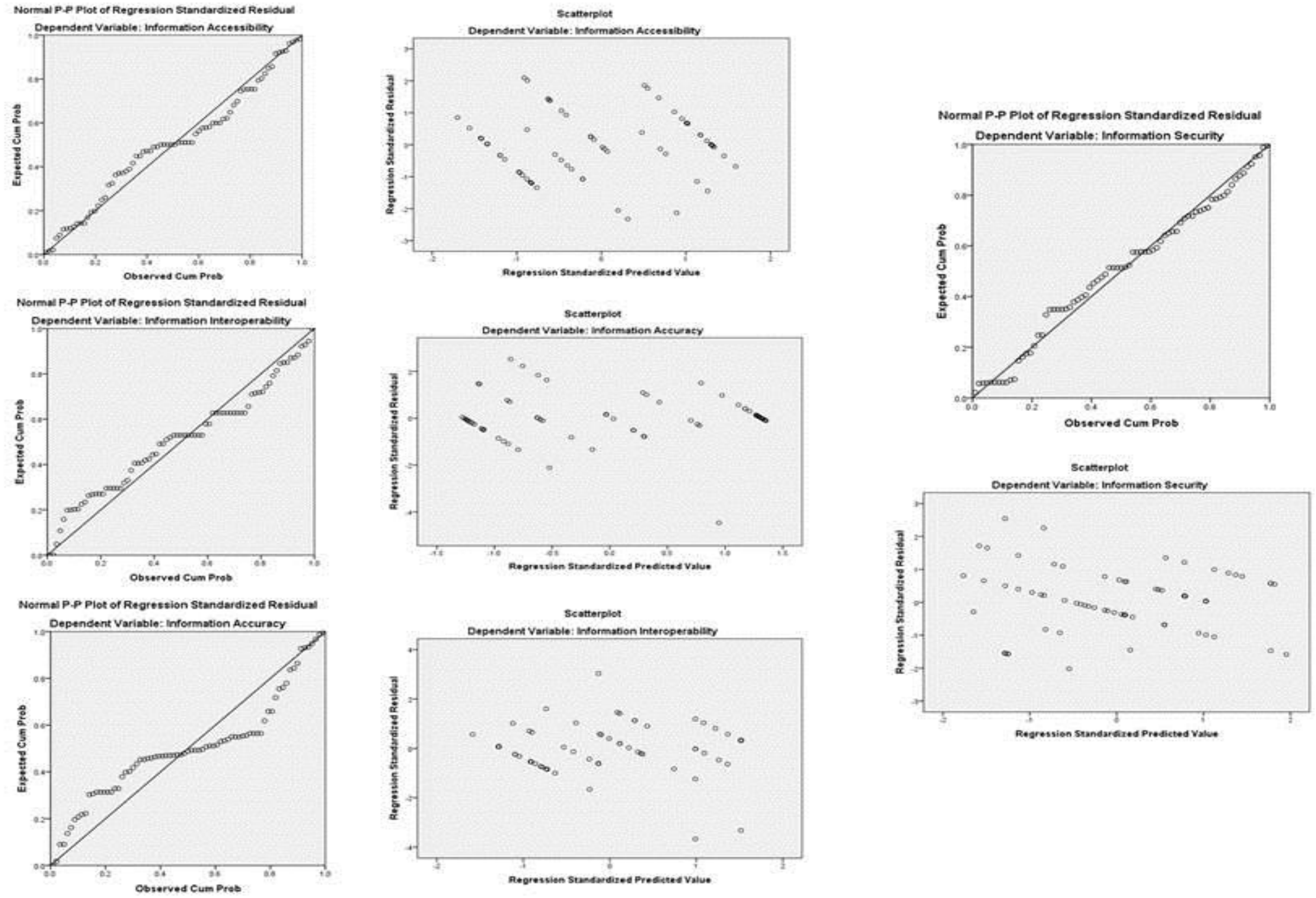


Figure 6-12 Normal P-P Plots Probability and Scatter Plots

6.5.4 Checking Reliability of the Data

As it has been mentioned in the Section 4.9.8 Cronbach's Alpha is one of the main test for measuring weather the scales are reliable or not. Cronbach's Alpha coefficient is the indicator to show the reliability of the scale. Pallant (2010) recommended at the first stage to check that all negatively worded factors in the scale have been reversed. In this survey all the factors worded in positive direction. It means that high scores indicate high satisfaction. The ideal correlation coefficient for reliable scale is 0.7(DeVellis, 2013) however According to Pallant (2010, p100) values above 0.7 are considered acceptable and values above 0.8 are preferable. Therefore Table 6-16 shows that Cronbach's alpha for for information quality items is 0.916 which is accepted.

Table 6-16Crobach's Alpha

Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
.916	.913	4

The standard multiple regressions was utilised to assess the ability of identified variables which are listed in three components to predict levels of satisfaction of information accessibility, information security, and information interoperability and information accuracy. Preliminary analysis was conducted to ensure data are distributed normally. All independent variables which are listed in component 1 entered to the model at two steps. In first step those variables that are identified with information accessibility satisfaction (dependent variable) and in second step those variables that are identified with information security (dependent variable). The independent variables which are listed in component 2 entered into the model regarding to information interoperability satisfaction as a dependent variable. And all independent variables under component 3 enter into the model under information accuracy satisfaction.

6.6 Chapter Summary

In this chapter multiple regression was employed to explore the factors influencing information accessibility, information security, information interoperability and information accuracy in the UK structural engineering sector. SPSS version 20 was utilised to conduct multiple regression analysis. The Pearson correlation (r) presented the strength of a liner association between independent and dependent variables. The significance level has been set to (0.3). The Pearson correlation examined all the ten independent variables in component 1 which shows that they are significantly related to information accessibility and seven out of ten independent variables in component 1 are significantly related to information security. All the eight independent variables under component 2 are significantly related to information interoperability and eight out of nine independent variables are significantly related to information accuracy (See Table 6-9).

The resulting R square was 0.865 for information accessibility, signifying that more than 86% of the total variance could be explained by the ten independent variables. The R square for information security was 0.311 which can be seen only as 31 % of the total variance which could be explained by six independent variables in information security model. The R square value was 0.752 for information interoperability model; signifying 75% of the total variance and could be explained by eight independent variables. And finally nine independent variables explained 90% of the total variances in information accuracy model. The bell shaped of histogram (Refer to Figure 6-11) and the normal probability (P-P) plot for all four regression models (Refer to Figure 6-10) with points basically clustered to the diagonal line indicate that the model is not violated the normality assumptions.

Multiple regression analysis was employed to each independent variable and its related factors under related component index individually. The analysis procedure was conducted under the selection criteria where; (Beta > 0.1 and Sig < 0.05). Three independent variables were selected into final regression model to predict information accessibility satisfaction including; 1- document control system 2- knowledge of BIM concepts training and 3- access to meaning of context. None significant independent variables selected to predict information security. Five independent variables were selected into final regression model to predict information interoperability satisfaction including; 1- online collaboration capabilities 2- various terminologies mapping 3- remote control on comments 4-understanding of BIM standards for recruitment and 5-BIM software application skills for recruitment. And finally four independent variables will be predicting information accuracy satisfaction including 1-performance prediction 2-contents of meeting retrieval 3-BIM software application skills training & 4- design optimization.

CHAPTER 7. CONCEPTUAL FRAMEWORK DEVELOPMENT AND RESEARCH DISCUSSIONS

The findings from the key themes from the literature review (chapters2&3), qualitative data analysis (Chapter 5) and quantitative data analysis (Chapter 6) are discussed in this chapter. The key challenges in structural engineering information management that were identified from the cross case analysis are summarised in this chapter. The existing applications of BIM in structural engineering information management were identified and the relationship between the key challenges and BIM dimensions in information management by the structural engineering sector of the UK are examined. Based on the analysis of the existing data, a conceptual framework for promoting the information quality management in structural engineering practice is developed in this chapter. This framework is designed to help decision makers in the structural engineering sector to implement BIM in order to improve the dimensions of information quality management. Finally, the chapter concludes with validation of the conceptual framework by interviews of industry experts and final modifications by incorporating the suggestions of these experts.

7.1 Information Management Challenges in the UK Structural Engineering Sector

From the literature review, it has been found that there is a lack of information quality in the AEC industry, and more so in the structural engineering discipline. Several dimensions for describing the quality of information in the construction sector have been shown in the literature review (Section 2.2.1). Information accuracy is the first dimension of information quality in the structural engineering discipline. This research highlighted the evidence from all interviewees of both studies, that accuracy of information is one of the key challenges in structural engineering information management in the UK. It was argued by interviewees in both cases that while working on their shared platform, they are unable to exert proper control on information accuracy. Appropriate calculations are needed in structural engineering and experts from both cases opined that in order to minimise the risks of errors and constructability in reports and drawings, appropriate control was needed in the structural information from conceptual design stage to the detailed design stage. In both cases it was felt that the complex architectural models, mixture of information captured from other disciplines and unstructured information from meetings that are in the form of dialogues and hand scratches are the main source of error.

Information accessibility is the second dimension of information quality in the structural engineering discipline. It has been shown in the literature review (section 2.2.1.1) that accessibility or availability of information in requested time is not appropriate in the AEC industry in the context of vast volumes and complexity of the information. From the qualitative case study (Chapter 5) it was revealed that information accessibility was one of the critical challenges in both Case 1 and Case 2. It was felt by the respondents in Case 1 that interaction between the internal and the external information management systems is the root cause of this challenge. It was felt that the inappropriate information synchronisation between the internal and external systems was the main cause behind inefficient information accessibility. In Case 2 it was felt that inappropriate retrieval of information from meetings, emails, telephone conversations and video conferencing was the main reason why the experts were dissatisfied with their information accessibility.

Information interoperability has been identified in the literature review (Chapter 2) as an important information management challenge faced by the AEC industry. The majority of interviewees from both cases held the view that one of the key challenges faced is the mapping of information between their applications and that of external stakeholders. It was pointed out by the interviewees that a lot of time was consumed due to interoperability issues and addressing drawing information that was exchanged or shared with the client, local authorities and contractors. From a study of Case 1 and Case 2 it was found that the main causes of lack of interoperability are different information formats that are not mapped to each other and changing client requirements from time to time.

Information security is another important information management challenge faced by the structural engineering sector. No evidence was found in the literature review that emphasised on information security in either the AEC industry or the structural engineering sector, however, the findings from the case studies and surveys in the present research reveals information security as a key challenge faced by the UK structural engineering sector. Information security is related to information accessibility, and most interviewees in both of the cases were of the opinion that the level of information accessibility should be controlled properly in their system by information system administration domain. The interviewees in case1 & case2 emphasised that prior to publication of any piece of information on the shared area it is not approved by the administration domain and the level of access to any information is not defined appropriately for each user.

When participants were requested in survey to rate the information management challenges in their organisation in respect of the level of significance, information accuracy was rated as the most critical challenge in the structural engineering discipline. The findings from the survey revealed that information accessibility (availability at requested time) was ranked as the second most important information management challenge faced by the structural engineering sector. Participants rated information interoperability that is data exchange between different applications as the third most important information management challenge. In terms of importance, data security was ranked fourth by these participants.

Table 7-1 Most critical challenges in information management in UK structural engineering discipline

IM key Challenges in Case1	**IM key Challenges in Case2**	**Key Challenges in Survey**
Information Accuracy	Information Accuracy	Information Accuracy
Information Accessibility	Information Accessibility	Information Accessibility
Information Interoperability	Information Interoperability	Information Interoperability
Information Security	Information Security	Information Security
Lack of Communication	Unstructured Information	Missing Verbal Dialogue Information
Inefficient Tacit Knowledge Repository		Lack of Information Management Standards
Tracking Information		Tracking Information

Lack of Standard Practice		

To develop a comprehensive understanding of the key information management challenges faced by the UK structural engineering sector, a detailed evaluation of the literature was done. It was found that most of the signs observed such as uncertainty in structural engineering decision making, lack of control of design information, presenting information and transfer information among design teams refer to information quality. It was emphasised in the literature review that information accuracy, information accessibility and information interoperability were the three most significant dimensions of information quality in the AEC industry. Moreover, in order to increase the level of understanding of the key information management challenges, this research identified the structural engineering sector as one of the main components of information producers in the AEC industry. Information security was identified by the participants of the case studies from the structural engineering department of two different large and multidisciplinary organisations as a key challenge in the hospital and arena structural design projects. Moreover, information security was also identified as a key information management challenge by participants from several small, medium and large organisations across the UK. Based upon the strong evidence obtained from the literature review, two case studies and the survey, this research therefore, categorised these four dimensions of information quality (accuracy, accessibility, interoperability and security) as the most critical information management challenges faced by the engineering sector in the UK. Other information management challenges faced by the structural engineering sector have also been identified in the present research. It was pointed out by some of the interviewees from Case1 that the tacit knowledge repository is not efficient, there are issues in tracking information and there is a lack of an efficient standard that can assist engineers in managing their information. Most of the participants in Case2 pointed out that serious issues are faced by their information management system while capturing verbal information generated either by meetings or by telephone/video conversations with the client, architect and other disciplines. Based on the findings from the survey “Missing Verbal Dialogue Information” lack of information management standard and tracking information is ranked as the fifth, sixth and seventh information management challenges in the structural engineering discipline.

Most of the critical challenges in structural engineering information management have been discussed up to now and the following section discusses the level of BIM implementation with respect to technological, workflows and human resources readiness perspectives in the current structural engineering sector and contribution of available BIM aspects towards the level of information quality.

7.2 BIM Adoption in the UK Structural Engineering Sector

The benefits of incorporating BIM technologies in the structural engineering information management domain have been investigated in both case1 and case2 studies in this research and by data collected by the survey method. The key tiers of BIM technologies such as the visualisation tier, file format standard tier, semantic tier and software tier are investigated in both of the case studies. This research identified the current application of BIM technologies in two structural engineering departments in large multi-disciplinary organisations in the UK. The influence of BIM technologies on key information management challenges have also been examined in this research.

7.2.1 BIM Technology Adoption

Available BIM technological aspects have been classified into four tiers in the literature review. These include the visualisation tier, file format standard tier, semantic tier and software tier. Moreover, available options in each tier have been discussed in detail. In the context of visualisation tier, it was shown in the literature review that designers have several options for viewing and presenting models to other project disciplines. The 2D model is a traditional method for presenting models whereby mere geometric entities such as points, lines, and spaces are provided. Review of the current literature reveals that more advanced technological options are available for structural engineering designers. The 3D objective-based model provides virtual physical information including size, location and shape, and additionally, location of components in relation to other components is defined in the model. BIM 3D objective-based model provides virtual physical information to display size, location and shape of the components. Additionally, the location of an objective in relation to the location of other objectives is also defined in the model.

The visualisation tier is the first tier of BIM technology determined in this study. Case1 analysis revealed that visualisation had an influence on information accuracy and comprised of three criteria that included performance prediction, design optimization and validating materials. Performance prediction and design optimization are indicated in both case1 and case2 which improve visualisation tier of BIM and improve accuracy of structural models. In case1 3D visualisation has been used and its use can improve the precision by which structural engineers can check the performance of structures. By simulating 3D models in failure conditions, structural engineers can test the resistance and response of models to extreme use. Kaner et al. (2008) argued that structural engineers traditionally waste time on checking drawings however, 3D object-based modelling could be utilised in structural engineering design projects to control potential geometry conflicts, inaccurate architectural models and complications to enhance the level of information accuracy. It was indicated through a review of literature that 4D model can support structural simulation to facilitate schedule analysis and 5D model also can support cost, resource information and hazard planning (Zhang and Hu, 2011, Zhang et al., 2015). In addition to nD CAD visualisation technologies and virtual reality which have been presented in the literature review, this research argued that the discipline of structural engineering requires a comprehensive overview on important criteria for decision making on the choice of visualisation technologies. In this context, the literature review (section 3.2.1) indicated that accuracy, ability for detailed simulation and performance predictions are the most important criteria for engineers in the choice of simulation tools. Moreover, this research explored the level of utilisation of visualisation in two cases and examined the interviewees' perceptions related to the criteria employed in the choice of visualisation BIM technologies and information quality dimensions.

The virtual design environment in case 1 represents mostly physical and functional aspects of structural components. The 3D CAD technology has been applied in the both case1 and case2 projects to support geometry details of structural elements and functional purposes of the components. However, the virtual design technology in case1 does not support time scheduling, cost and resources and structure safety planning. Moreover, most of the interviewees held the view that in order to support business goals the appropriate virtual data environment should cover product models, work process cost and value of capital investment. It was indicated by interviewees in Case1 that both design optimisation and validating material criteria impact upon the accuracy of structural information. Material usage can be controlled by applying innovative simulation designs and costly mistakes can be avoided by validating material and size choices of components. Case 2 also revealed that visualisation also influences accuracy. Interviewees from Case 2 stressed that apart from performance prediction and design optimisation, other criteria such as presenting critical zones and simplification help improve the visualisation tier thereby enhancing the accuracy of the structural model. Analysis of Case 2 revealed that simplifying the structural model and including the critical zones from the visualisation point of view can play an important role in performance prediction. Critical zones are those parts of the model that are under the greatest stress. Displaying critical zones and marking their stress and displacements on the structural model would greatly assist structural engineers in taking more accurate decisions.

Findings from the survey also revealed that in terms of the visualisation tier, 2D CAD drawing and 3D modelling were highest weighted and utilised tools in the UK structural engineering sector. 4D modelling, 5D modelling and virtual reality are used occasionally by structural engineering companies in the UK. The results from the case studies and survey indicate that structural engineering organisations in the UK do not employ the full potential of available visualisation technologies to model information beyond the physical and functional aspects of components. Nevertheless, most of the interviewees in case1 and case2 projects were of this opinion that modelling with smart virtual design technologies that can support time schedule, cost and resources and safety planning would enhance completeness and accuracy of their information presented.

Capabilities for design optimisation, components performance prediction and model simplification are considered to be the key drivers of information accuracy for the adoption of visual technology by the structural engineering discipline. Moreover, the survey measured the relationship between most of the key criteria for the adoption of BIM technologies and level of information quality satisfaction in the UK structural engineering sector. The results of the survey indicate that the most influential factors towards the adoption of visualisation technologies to enhance the level of information accuracy are the capabilities for design optimisation and performance prediction. Model simplification was found to be another significant factor that should be considered in the adoption of visual technologies.

This study has determined the file format tier as the second tier of BIM technology. IFC and CIS/2 have been assessed in the literature review (Section 3.2.2) as two main and important open information model standards for use in the structural engineering discipline to support interoperability. IFC and CIS/2 are not restricted to a single application and most of the available structural analysis and design applications support IFC and CIS/2 interoperability. This research investigated the level of file format technology usage in the UK structural engineering sector. In terms of file format, CAD drawings, PDFs, Microsoft office files and images are the most commonly used file formats in both case1 and case2. Experts in both Case 1 and Case 2 expressed two main considerations regarding the file format tier, and these are firstly the type of file and secondly the file or document management system.

The main input information into the structural engineering information system in both Case 1 and Case 2 was architectural drawings that include geometry to present structural component positions, initial sizing, initial considering materials, assembly of the building, the position of the construction works, access and layout of the site. In Case 1 and Case 2, the structural engineers were responsible for providing components drawings, bill of quantities and reports. Thousands of files are produced during the conceptual and detailed design phases to support all drawings, quantities and reports information. It is revealed from the case study that most of the input information transfer from architect to the structural information system by Dwg file format and other portion of information are mostly dialogue. Dialogue information often captured from other disciplines during meetings, texts in emails or via telephone conversation. The output information in Case 1 and Case 2 were not merely Dwg format but also structural engineers deliver some information via image (JPEG), PDFs and spreadsheets (xlsx) for bidding, construction or reporting to client and local authority purposes.

In both cases, most of the structural engineers were not familiar with open file standards such as IFC and CIS/2. Case study findings indicate that the main challenge is not merely to adopt efficient file formats, but also it is necessary to employ efficient technology to support file/document management towards enhancing accessibility and interoperability of information.

This research examined influential factors in file/document management technologies which contribute in promoting information quality particularly in the structural engineering discipline. Case study analysis in this research indicated that it is very important to improve information management systems in terms of simplified accessing into information. The simplified accessing file management system could provide a simple interface for structural engineers to determine required information and track files or documents that are received or were created previously. It was also revealed from the case study that promoting simplified accessing is a factor that contributes towards information accessibility in structural engineering information management. The case study findings also listed more considerable factors which are recommended to be considered in adopting file/document management technology to promote information quality in structural engineering. The second factor is user notification. The case study emphasized that notifying users of changed or eliminated information can have a significant contribution towards accuracy and accessibility of information which are attached to files or documents in the system. The third factor influencing the information quality that was emphasised in both the cases of this research was third party secured access. Experts in both cases emphasised on secured file management technology to select files to be securely viewed by an external user who is not a part of the internal organisation team. This factor contributes not only on information security but also promotes information accessibility for external users, particularly the client to access structural design and reports information by securing username and password. The fourth and final factor influencing the information quality that was revealed by both Case 1 and Case 2 was integrated search function. Both the case studies showed that developing an enabled database that was searchable by relative key words has a great impact on information accessibility for structural engineers. Structural engineers require information related to geometry, available material in region, sustainability reports etc., and this information would be shared in the integrated database and are sensible to some keywords to be searchable and accessible. All the above factors in file and document management tier were put to survey respondents to compare their level of satisfaction of these factors and their level of satisfaction of information quality dimensions. The survey results show that simplified document control is appreciable and significantly contributes to information accessibility in structural engineering information management.

The semantic tier was determined as the third tier of BIM technology in this study. Semantic web emphasised on enabling information understandable not only to humans but also to machines. It was established through review of the literature that, semantic web and anthology engineering technologies have a significant role in improving information quality in the AEC industry. Semantic web relies on several information technology resources and languages which are explained in section 3.2.3. Anthology engineering forms the heart of the semantic web. Anthology engineering develops an agenda for modelling entities, concepts and relationships between them through machine understandable languages. It was indicated through a review of literature that structural engineering entities and concepts, and relationships between than can be created, described and explained through ontology engineering methodology (See Figure 3-6). Literature review also shows that the heart of ontology engineering is taxonomy and library to support the semantic exchange of knowledge in an integrated structural design environment. Several efforts to develop and improve different components of semantic web such as vocabulary library to promote interoperability in the AEC industry were also highlighted in the literature review. This research, however, tried to fill the gap in investigating semantic web adoption in structural engineering information management system.

A study of both Case 1 and Case 2 revealed that web of meaning (semantic web) is necessary to be employed in their current projects to accelerate the information quality management procedure. Key factors that should be considered in structural engineering information management systems to adopt efficient web of meaning to obtain information were examined in the case studies of this research. The first factor is terminology mapping. Both cases' interviewees argued that structural engineers and architects use different terminologies for same element or concept. The case studies carried out in this research revealed that the information requirements for both of the structural engineering departments were achievable through the internal database system and internet webs. Experts suggested adopting analogy technologies to conceptualise structural and architectural terminologies in intranet database and adopting semantic webs which cover different terminologies in the context of architectural and structural terminologies. Case study findings reveal that Key word search is the main tool for requesting information from the intranet database and online web services. Structural engineers can find titles, figures, links and tables by searching key words in the search engine, however, they cannot obtain the information by the same term of reference to different concepts. While structural engineers and other construction stakeholders would understand those terms, the IT programme is unable to distinguish the different meanings in different sentences. Case study in this research also suggested that tagging different concepts by different URIs will cover different terminologies and it would increase accuracy and accessibility to meaning in the context of information.

Survey respondents were asked to evaluate all the factors in the semantic tier and were requested to compare their level of satisfaction with these factors and their level of satisfaction with the dimensions of information quality. The results of the survey show that various terminologies mapping factor which has been examined in case study findings appreciable and significantly contribute to information interoperability. Moreover, it is also indicated by the survey findings that access to meaning of context factor has a substantial and significant contribution towards information accessibility in structural engineering information management. The level of semantic web usage to find the specific context of the respondents was also revealed by the survey findings. Respondents were asked to rate how often they used the web of meaning to find specific information. From the survey study, it was found that in the UK, the majority of the structural engineering organisations either does not utilise semantic web at all, or use it rarely. It can thus be interpreted that the rate of semantic web usage by the respondents of this survey ranges between rare and sometimes. It was also found from this survey that the respondents preferred to share their documents through cloud based platforms (e.g google drive, drop box and Microsoft drive) instead of using their web channels. Specifically, the respondents stressed that the utilisation of cloud based platforms ranged between sometimes and often, but the sharing of documents over the web channels ranged between rarely and sometimes in their organisations.

The fourth tier of BIM technology determined in this study is the software tier. It was evident from the literature review that in the recent years a variety of structural analysis and design packages have become available. The development of these software packages is based upon BIM concepts. However, structural engineering organisations face a vital challenge in adopting the appropriate software with consideration to information quality. Some factors that should be considered in adopting structural engineering software packages for BIM implementation also indicate in the literature review. In terms of the choice of structural engineering software package and BIM implementation, conceptual design supports through structural engineering applications was also emphasised in the literature review. Currently, most applications are not facilitated well to support best solutions within various design alternatives in the conceptual design phase. Therefore, in structural engineering, there is poor quality of information accuracy in the conceptual design phase. The findings from the case studies indicate that those structural engineering organisations which adopted compatible version of the software are in a better situation with respect to the interoperability dimension. Compatible version factor of structural engineering software contributes to exchange models to other disciplines and they can run in their applications without modifications. Finally the case study findings pointed to capability of software to gain access to rich product libraries factor that intensely promote information accessibility. It is also very important to ponder on the compatibility of the software. The compatibility with internet to update the model geometry, material properties, loading varieties, analysis types and design codes is a significant criterion to enhance information accuracy and information accessibility.

Some structural software packages and their exchange and interoperability capabilities (Table 3-3) have been described in the literature review. Findings from the survey show that over half of the structural engineering organisations in the UK do not have their own software packages for analysis and design. Thus, these organisations incorporate software packages that are available in the market. The Revit structural software is the most popular structural analysis and design package among structural organisations based in the UK. This is followed in terms of popularity and acceptability by the Tekla structure and Beantly structure. All the factors in adopting structural analysis and design packages that were explored from the literature review and case studies were put to survey respondents to compare their level of satisfaction of these factors and their level of satisfaction of information quality dimensions. The survey results did not show significant contribution of those factors to information quality. The survey sample presents small, medium and large structural engineering organisations however; case studies merely can present large multi-disciplinary structural organisations. Therefore this research results show that structural departments in large multi-disciplinary organisations require to consider three main factors including; conceptual design capability, compatible version and product libraries to enhance information accessibility, information accuracy and information interoperability.

Significant criteria in adopting BIM technologies have been described in four tiers. Those significant criteria are explored from literature review and case studies and the contribution of those criteria into information quality are assessed from the case study and survey. The next section of discussion chapter presents a discussion on literature review, case studies and survey results themed around BIM workflow adoption in structural engineering discipline.

7.2.2 BIM Workflow Adoption

This section of the chapter presents the discussion of the key factors in adopting BIM workflows findings emanating from the literature review (Chapter 3), case study analysis (Chapter 5), and survey analysis (Chapter 6). The literature review presents relevant BIM-based workflows to achieve successful level of BIM implementation. Lack of efficiency in workflow causes failure and obstruction to successful BIM implementation. Conducting BIM could be a complex process in the lack of efficient workflows for the AEC industry and structural engineering industry as a part of this industry requires proper BIM-based workflows to implement BIM-based intelligent information management among their organisations.

Studies of the most typical BIM workflows, both in the UK and worldwide (Section 3.3) are presented in the literature review. The BS1192 standard is the first workflow and is applicable to all stakeholders, including structural engineers, who are involved in the process of construction information management at any stage of its life cycle. This workflow entails prior allocation of the roles and responsibilities of structural engineers and other design participants. Each of the project participants creates their model in a work-in-progress (WIP) environment in an early stage of BIM-based information management. The suitability of the model should be evaluated before sharing the model in a published document environment. The second workflow is PAS1192, and this standard offers information exchange management in integrated information delivery through the entire lifecycle of the construction project. The employers' requirements (EIRs) determine which document and model need to be provided at any specific project phase. Project delivery team should give consideration to review that all necessary documents have been set up and approved and that the information management process are in place. The third workflow is Information Delivery Manual (ISO 29481), and the components of this workflow are exchange concepts, exchange requirements and process map. This standard emphasised on IFC schema as a fundamental element to take-up BIM and for exchanging information between various BIM users. According to this workflow, information requirements should be determined at an early stage of information management. Moreover, the consumer of the information and software that supports information creation and delivery solutions should also be described. Information determined in the exchange requirement layer can support activities to develop a process map.

Some of the available workflow for BIM-based information management in the AEC industry have been described in the literature review, but, from the case studies it is evident that different structural engineering organisations have different requirements, characteristics and capabilities. Therefore, a specific BIM workflow cannot be recommended to all structural engineering organisations. This research explored the key factors that should be considered by structural engineering organisations to adopt efficient workflows or develop their own organisational workflow to enhance their level of information quality.

Organisations studied in Case 1 and Case 2 were in different stages of adopting BIM-base information management workflows. In case1 whereas the organisation had established its own information management workflow, the company in Case 2 was in the process of developing its own BIM-based information management workflow. Although the organisations studied in the two cases were large in terms of size and turnover, the costs involved in adopting technology is a considerable issue at their management levels. Thus, both organisations tried to develop their workflows based upon their budget. It was indicated by the Case 2 study that BIM workflow should be developed in respect to internal culture and budget in order to be applicable to the organisation. Moreover, interviewees from the case2 study recommended that collaboration with industry peers and understanding their views on BIM implementation would be of great help in developing an efficient workflow.

As already mentioned, the organisation studied in case1 had established its own information management workflow. The key persons responsible for developing this framework were the design manager and BIM manger, who had the cooperation and assistance from the IT department. The information management process was designed in three stages: information producing, information sharing and information evaluation. The workflow adopted in case1 was very close to BS1192 protocol due to which each individual design participant (structural engineers, architects and building services designers) creates their model in a work-in-progress environment first. Subsequently, building design models are centralised to one model and uploaded to document control system. The study of case1 shows that the workflow model covers management of 3D drawing model however there is a need to have a protocol for unstructured information to be accessible accurately and to be updated regularly. The evaluation process does not take place on the shared document control system in case1. Design participants discuss about the model and reports in meetings and remote electronic comments were not considered in the workflow. In Case 1 it was found that many dialogue comments during meetings are lost due to a lack of a remote electronic comments system leading to a reduction in information accuracy and information accessibility. Based on the workflow employed in Case 1, participants were able to compare their designs with previous projects but the evaluation system was not consistently applicable.

The findings of Case 2 show significant factors and requirements in each phase of structural engineering information management with respect to enhancing information quality dimensions. Case2 findings show that potential BIM-based workflow can be categorised into input, evaluation, documentation and publish stages. On the input stage, there are two significant factors which include access to verbal information (including meeting, telephone conversation and clear documentation description) and clear document description. Capturing and acquiring verbal information was considered in both Case 1 and Case 2 as a controversial concern. During the meetings structural engineers discuss many design solutions with architects, client and building services designers and the verbal solutions are recorded either in text or sketches drawings. It was argued in both the cases that this is not an efficient method. It was recommended by Case 2 to consider in developing standards or guidelines to show efficient ways of capturing and storing verbal information and this could affect information accuracy and information accessibility. The correct way of file or document description in a system could also impact on information accessibility and accuracy. Therefore, it is recommended to consider appropriate file/document description method to store information precisely and more achievable in information management system.

Case 2 also revealed that in the evaluation and documentation stage of BIM-based information management, remote comments on documents, document control system and matching final information with client's requirements are very critical points in adopting BIM workflow. Case study findings claimed that the inclusion of standard methods of leaving comments on report information and drawing information, and systems for document control in the BIM workflow would help in maintaining the accuracy and accessibility of structural information management. The final stage of the BIM-based workflow for structural engineering discipline is identified as publishes stage by studying case1 and Case 2 projects. As it has been mentioned in the above paragraphs, BS1192 is also defined publish stage as a last stage of BIM-based information management process. Case study findings indicate that all project stakeholders including client, architects and local authorities should be provided access to the published information that are created by structural engineers and a system of accessing into general and technical documents should be designed and this would have a positive impact upon final interoperability with stakeholders.

Commonly available BIM workflows that were discussed in the literature review were put up to the survey respondents to gauge the level of BIM utilisation in the UK-based structural engineering sector. The survey findings show that over one-quarter of structural engineering organisations in the UK have not used any BIM workflow in their company. Almost 10% of the UK-based structural engineering organisations have developed their own workflow for adopting BIM and for their information management process. Over half of the structural engineering organisations in the UK had adopted popular BIM workflows standard (BS1192, PAS1192 and ISO29481) of which the PAS1192 was the most widely used BIM workflow in the UK structural engineering discipline. All the factors in adopting and developing BIM-based structural information management workflows that were explored in the literature review and case studies were put to survey respondents to compare their level of satisfaction of these factors and their level of satisfaction of information quality dimensions. The survey results indicate that the document control systems were selected as a significant factor that contributes to information accessibility and remote control on comments significantly contribute to information interoperability.

The significant criteria in adopting BIM workflow are discussed in this section. Those significant criteria are explored from literature review and case studies and the contribution of those criteria into information quality are measured from the case study and survey. The next section of the discussion chapter presents a discussion on literature review, case studies and survey results themed around human resource readiness criteria in BIM adoption in the structural engineering discipline.

7.2.3 Human Resources Readiness

This section of the chapter presents the discussion of the key factors in recruiting and training structural engineers to adopt BIM based upon findings emanating from the literature review (Chapter 3), case study analysis (Chapter 5), and survey analysis (Chapter 6). Many authors reviewed in the literature point out that human resource is a key obstacle in adopting BIM in AEC industry. It was argued by many researchers that the skills and opinion of human resources about using technologies and processes would influence the success of BIM implementation in AEC organisations. Literature review also indicates that AEC organisations are suffering from a lack of employees who are adequately trained in the use of BIM. The skills in BIM technologies and understanding of BIM workflows are recommended as a key priority for recruitment and training human resources for BIM implementation. There are some high rated BIM-oriented courses to make construction participants ready by training in colleges and universities, however; acquiring BIM talents is still a critical challenge for organisations. Therefore, this research conducted two case studies to investigate on structural organisations' strategies for acquiring BIM human resources talents.

Investigation of two structural engineering departments in two multi-disciplinary construction organisations shows that lack of key skills in using BIM technologies and workflows is a critical challenge even for large construction organisations with a substantial budget. Both Case1 and Case2 revealed that human resources strategies were not marched efficiently with BIM aims. Both cases argued that their senior structural engineers are very reluctant to use new BIM-oriented technologies and workflows and costs of human training are considerable in their organisations.

Case study findings show that the human recruitment functions in the UK-based large structural engineering and multi-disciplinary construction organisations are conducted through internet. Structural engineers post their resume on job hunting agencies' websites or through social media such as LinkedIn. The most influential criteria for structural engineering job applications are categorised into education and experiences. Providing bachelor degrees in civil engineering, master degree in structural engineering, construction management and completed courses related to integrated design and BIM have had a positive influence on the recruitment applications in case1. However, case2 does not consider BIM skills as a strong influencing factor in their recruitment process. Most of the participants in case2 argued that their organisation hired a BIM manager however, his role and responsibilities are not well defined and he acts as CAD manager. BIM cannot be adopted to improve information quality merely by employing a CAD manager. The findings from case studies recommended listing of BIM software application skills, knowledge of BIM concepts and understanding of BIM workflow in their job description for recruitment. This would impact upon information quality and the accuracy, accessibility and interoperability of information would be improved.

As it has been mentioned in the above paragraph, having strong experience is also an influential factor in the recruitment strategy in both case1 and case2. In both cases mostly contractors have technical structural engineering design experience, however, participants highlighted that having experience in BIM software application, BIM concepts and BIM workflows would impact on information quality in their organisations. Findings from both case1 and case2 studies also emphasised on conducting an internship program for graduates structural engineering professionals. It is recommended by experts from both cases that during the internship programme in structural engineering candidates can use the opportunity to increase their knowledge in BIM software application skills, knowledge of BIM concepts and understanding of BIM workflows. It could influence on their communication, document management, virtual design models and building performance analysis and thereby the accuracy, accessibility and interoperability of information will be improved.

Findings from the survey also emphasised on the influence of BIM-oriented recruitment and training in structural engineering organisations' information quality. According to survey findings, there is a strong and significant contribution of consideration of skills in BIM standards and BIM software applications during recruitment on information interoperability in structural engineering organisations. Survey findings show that training in BIM software application contributes strongly and significantly towards information accuracy in structural engineering organisations. And finally training BIM concepts in internship programme for graduated structural engineers can contribute strongly and significantly to information accessibility in structural engineering discipline.

To sum up, this section presents a deep discussion of key information management challenges and key factors in BIM implementation and contribution of those factors on information quality in structural engineering discipline. The identified key factors are components of the conceptual framework and the relationships between factors can contribute to enhancing information quality management in structural engineering discipline. The next section presents the conceptual framework components and relationships between those components and it's followed by validation to amend initial conceptual framework by interviewing experts.

7.3 Proposing Conceptual Framework

The findings from previous chapters including literature review, case studies and survey, have contributed in this research to gain a better understanding of key themes and the relationships between the themes which can present the key components of the conceptual framework. The findings from literature review give a broad view to the researcher to scope down the research focus on key information quality dimensions. The majority of the evidences in literature review emphasised on AEC industry challenges and the findings from case study and survey also emphasised on three key challenges as shown in the literature: information accessibility, information accuracy and information interoperability. In addition findings from cases studies and survey shows that structural engineers have one more key challenge which is information security. The literature review shows that the stakeholders of the AEC industry have not sufficiently availed the benefits from BIM, and the findings of this research confirms that in the case of the structural engineering discipline in the UK, even the large organisations with substantial budgets have not derived the maximum benefits of BIM in terms of technology, workflows and human resources. The criteria in adopting BIM which can significantly contribute to enhance the level of key information quality dimensions are explored as themes. When a specific theme or factor occurred in both cases it implies that it is a common concern to the structural engineering stakeholders. The key themes and factors derived from research findings is utilised to develop a conceptual framework for adopting BIM in structural engineers discipline in the UK.

The aim of this research is to develop a conceptual framework to enhance the present contribution of BIM implementation in structural engineering information management in the UK. The proposed conceptual framework indicates the key concepts or factors from literature review, case studies and survey data collection. The relationships of the concepts and key factors are presented in the conceptual framework. The challenges of poor quality of information in structural engineering information management and understanding of the key criteria in adopting BIM to enhance the level of information quality can be addressed through the proposed conceptual framework.

The findings from literature review leads to the development of the initial conceptual framework (See Section 3.5). The initial conceptual framework limited the scope of this research to contribution of three key BIM domains (technology, workflows and human resources). The aim is to address key dimensions of information quality. As it is presented in Figure 7-2, conceptual framework is categorised in three BIM domains. The available options which are available for structural engineers are classified under each BIM domains. The case studies and survey findings explored the main concerns of structural engineering stakeholders about information management, and majority of the participants finalised the key information management challenges under four main information quality dimensions. Case studies and survey findings also explored the key criteria or factors that would significantly influence on those dimensions of information quality. The qualitative data analysis explored most of the themes mentioned by the interviewees in their statement as key criteria. The influence of those criteria on information quality dimensions were also indicated by the interviewees during the qualitative data analysis. Quantitative data analysis from the survey had access to a larger sample of population. For collecting quantitative data, participants were asked to rate the extent of satisfaction with BIM adoption criteria in their organisations and how they were satisfied about the dimensions of information quality. The relationship between variables explored by quantitative data analysis and cross cases between qualitative data and quantitative data leads to final relationships between BIM adoption criteria and information quality dimensions.

The proposed conceptual framework is a symbolic presentation and snapshot image of BIM-oriented factors which significantly influence information quality in the structural engineering sector. The proposed conceptual framework provides a schematic representation for enhancing information quality in structural organisations (See Figure 7-1). By implementing this conceptual framework, structural engineering organisations would be able to identify the available options in BIM technologies, workflows and human resources readiness strategies. Moreover, the most influential factors within each BIM dimension and the interconnectivity between influential factors in implementing BIM and information quality dimensions are shown in this framework. Although a large number of BIM-oriented technologies, workflows and organisational readiness are available in the literature and in the market, it is a critical challenge for structural engineering organisations to take appropriate decisions on the adoption of BIM technology. This framework provides them with the opportunity to have a better understanding on which factors should be considered in adoption of each BIM option and how that factor impacts upon information quality as the most critical challenge in the structural engineering discipline. In this Framework colour coding is used to explain the influential factors to specific information quality dimensions (See Figure 7-1).

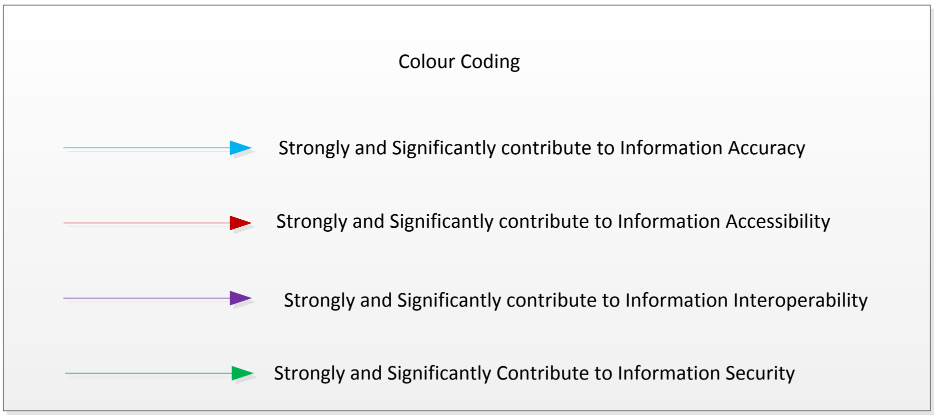


Figure 7-1 Colour Coding in Conceptual Framework

This framework relied upon an initial conceptual framework that was developed previously based upon a review of the literature (See Figure 3-14). Accordingly the proposed conceptual framework is categorised into three main BIM domains which are; technological domain, workflow domain and human resource domain. Technological BIM options contribute to series of targets including visualisation, file format and file management, semantic and software. These targets contribute to specific information management activity in structural engineering sector. The main BIM targets and options were identified through literature review and primary data collection aided this research in identifying factors that are influential in adopting technological BIM-oriented options and the contribution of each factor on information quality dimensions.

The conceptual framework developed in this research is based upon three domains. The first is the BIM technology domain, the second is the BIM workflows domain and the third is the BIM human resource domain. Having three different aspects, these domains have different options that affect specific targets in the information management system and ultimately address the key challenges that affect information quality.

The BIM technology domain has four options, the first include 3D, 4D and 5D virtual realities. This option is targeted at visualisation and is entrusted with drawings and rendering of reports. It impacts performance prediction, design optimisation and model simplification and thereby addresses the accuracy component of the information quality challenges. The second option is CAD-IFC-CIS2-COBie that targets file format and management. This option deals with the exchanging of information and addresses the document control systems, online collaboration capabilities and user notification. Thus this option has effects on the accessibility, interoperability and security aspects of information quality. The third option is the semantic web that targets semantics and deals with accessing information. The factors affected by this option are access to meaning of context, keyword search engines various technologies mappings. Accessibility and interoperability are the two key information quality challenges that are addressed by this option. The fourth option is Tekla-Revit-Beantly, or the organisation’s own software that targets the software component of the BIM technology. This option focuses on analysis and design and is associated with capability and conceptual design, version of software mapping and product libraries. The information quality challenges addressed by this option include accuracy and interoperability.

The BIM workflows domain also comprises of four options. These include the BS1192 workflow, the PAS 1192-2 workflow, the ISO29481 standard and various in-company workflows designed and used by specific organisations. These workflows have a basic structure that is common to all, and consists of input, exchange, evaluate and publish functions. The input function captures the requirements specified by the client and the local authorities, the model proposed by the architect and the contract requirements. All the information that is input in the system is then processed by the exchange function. Here the input data undergoes documentation, description, modelling and dialogue to ascertain the exact requirements of the project. Then a common data environment is created that is kept up to date. In the evaluate function, the data is verified by the client in the shared area and remote control comments are added. Finally, after the evaluation the data is published in the appropriate format using the publish documentation function. Proper design and implementation of this domain would impact all the four key challenges of information quality that are accuracy, accessibility, interoperability and security.

The third domain is the BIM human resource domain. It consists of two options, BIM-based job description and BIM internship. The BIM-based job description targets the recruitment process and seeks to employ structural engineers who have skills in BIM software application, have a thorough knowledge of BIM concepts and have a good understanding of BIM standards. Attention to these requirements in the recruitment process would ensure that information quality challenges related to accessibility and interoperability are addressed. The second option is BIM internship, these targets training within the organisation and seeks to develop BIM software application skills, knowledge of BIM concepts and an understanding of BIM standards among newly recruited structural engineers. Adequate focus on this option would help address challenges related to accuracy and accessibility.

Thus the development of the BIM conceptual framework as outlined above would help enhance the information quality in structural engineering organisations. This framework would address all the key issues and challenges that affect information quality, and would eventually improve productivity and profits for the structural engineering industry in the present highly competitive environment of the AEC industry of the UK.

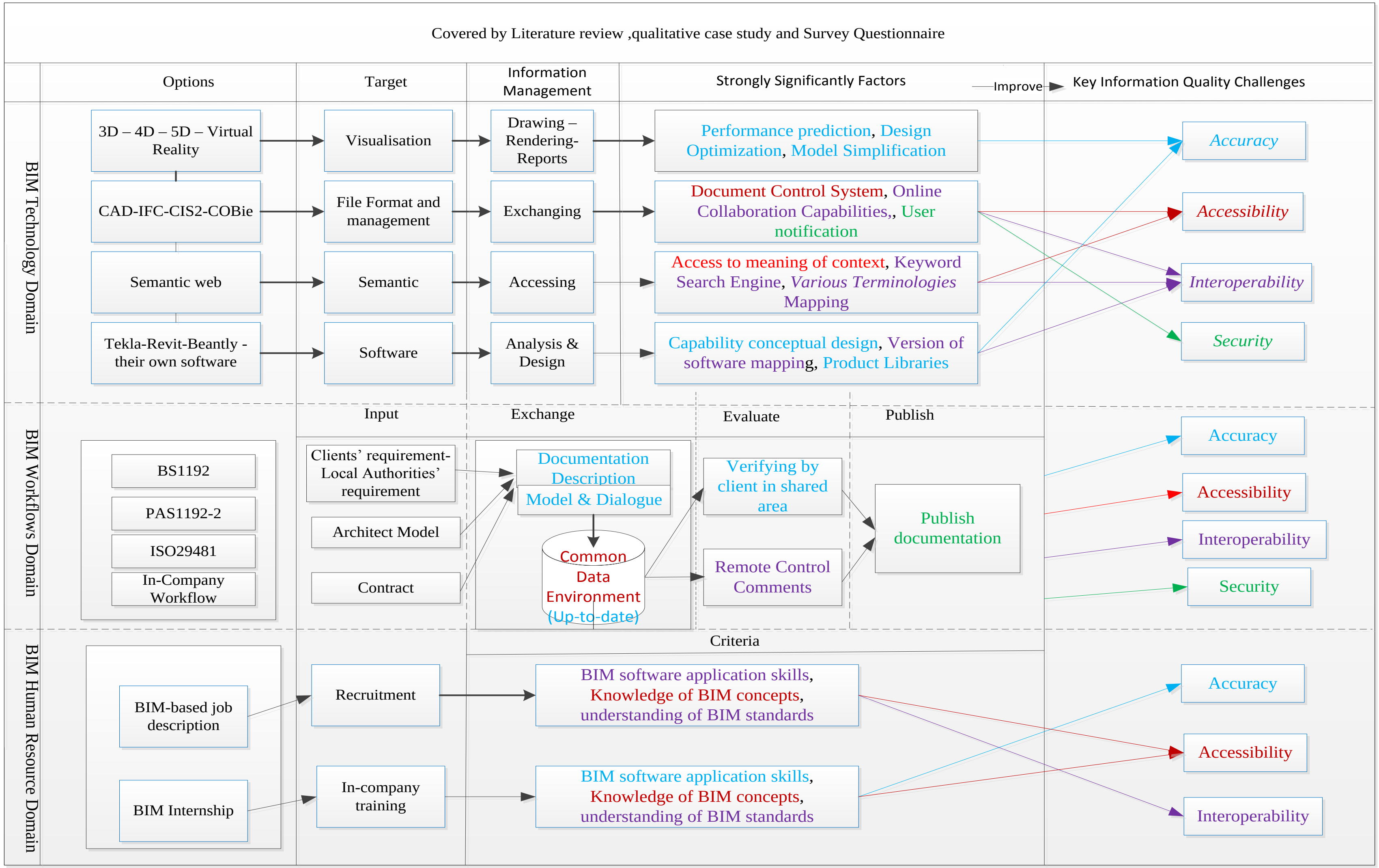


Figure 7-2Conceptual Framework

7.4 Conceptual Framework Refinements and Validation

So far, the proposed conceptual framework has been discussed in detail from all the sources of information, such as literature review, case study and survey that were employed in the present research. Six BIM experts were interviewed to validate the findings of the present research in practice. These experts had relevant experience in the structural engineering discipline and had several years of experience in implementing BIM in the AEC industry in the UK. Of the six interviewees, three were academic professors and had several years of experience in the development of BIM for UK based AEC industry. The other three were structural engineers and had been practicing in the field of structural engineering in the UK for several years.

The interviews aimed at finding the views and opinions of the experts about the proposed framework and to seek their expertise to ascertain whether the framework covers all significant aspects of BIM implementation. The experts were asked to air their views about the ease of comprehension of the proposed framework by structural engineers and other practitioners in the industry. These experts were encouraged to comment on the applicability of the framework in structural engineering practice. Finally, the experts were asked if the proposed conceptual framework had sufficient novelty for the literature and could contribute to the body of knowledge.

The interviewees were asked if the conceptual framework was comprehensive and included all required features. They unanimously held the view that the main issue of information management, that is, information quality has been addressed by the four key aspects of the conceptual framework. By and large the experts felt that the three domains of BIM, that is technology, process and human resources were incorporated in the conceptual framework and the main components of these each of these domains were included thereby having a positive impact upon information quality. In this context, one of the interviewees stated that:

> "…*You have very interesting conceptual framework. I like mapping of the different criteria for BIM and three categories that involved around BIM. I think it covers some really comprehensive issues...*"

In terms of the ease of understanding the proposed conceptual framework, the experts held the view that the proposed framework was unambiguous and could be easily understood by the end users. Some recommendations were made by the experts to improve the conceptual framework in order to display a clear relationship between the various factors. It was felt by the experts that the use of colour coding in the conceptual framework enabled a better understanding of the relationships between the BIM factors and the dimensions of information quality. One of the experts expressed his views about the colour coding as follows:

> *"...In terms of the relationships I think, I am quite happy; I can say the colour codes work for me. I don't know about everybody else but I can clearly make the connections..."*

In terms of information security, half of the interviewees held the view that BIM does not have any direct contribution to information security but the platforms have user groups and roles that defines the information that can be accessed from the databases by individual users.

> *"...When we speak about security we mean wrong people should not access to specific information. And user notification here means that it makes sure you have correct correction and it more about accuracy*…"

Terminologies and relationships between some factors in the proposed conceptual framework were recommended by some of the interviewees. One expert pointed out that the addition of a taxonomy that explains the definition of each terminology used should be attached to the conceptual framework. This expert stressed that information accuracy should be explained in greater detail, and reliability, completeness and usability should all be included in the information accuracy terminology. Four out of six interviewees also argued that the user notification refers to comments and feedback and they did not agree that user notification could positively contribute to information security, and they pointed out that user notification capability can positively contribute to information accuracy. One the interviewee regarding to this point commented by saying:

> "*…I am thinking you have user notification which is very much same as comments. This is also common feedbacks. It's not a mistake its connection but I think user notification in much improve information accuracy..."*

In terms of contribution to knowledge and novelty, all the interviewees were this opinion that this conceptual framework can contribute to industry to clear misunderstanding and complexity of BIM. Those experts expressed that this proposed conceptual framework has covered many key aspects of BIM and structural engineers can understand the key issues and factors that can contribute to key issues clearly. This conceptual framework can aid structural engineering industry in decision making based on BIM-oriented factors. Moreover, all three Academic professors argued that in terms of a combination of all BIM factors and relationships between factors this conceptual framework is sufficiently novel in the literature. For instance, one of the interviewees pointed out that;

> *"...I think most of different aspect you can find in literature, but the combination of factors are sufficiently novel. It will be very difficult to invent in this area, that you cannot find similar ideas in literature. But the combination itself is sufficient in my opinion..."*

Based upon these recommendations, the conceptual framework was further refined as shown in the Figure 7-3. The author holds the view that this conceptual framework would serve to guide structural engineering organisations that are desirous of implementing BIM, and also help those organisations who are interested in implementing BIM for enhancing their information quality.

7.5 Recommendations for Using Proposed Conceptual framework

Figure 7-3 illustrated the flow diagram of how the BIM adoption can contribute to information quality in the structural engineering sector. Structural engineering organisations are recommended to consider all three key dimensions of BIM together (BIM technology, BIM Workflows and Human resources readiness). As presented in the proposed conceptual framework (See Figure 7-3), the structural engineering organisations have several options in terms of technological and workflows, however, the critical point is how they can select the most efficient option to enhance information quality. The technological and workflows BIM choices can be updated on a day to day basis; however, the proposed conceptual framework (See Figure 7-3) presented the key criteria that structural engineering organisations can consider to enhance their information quality. The following paragraph recommends a step by step approach to structural organisations with respect to implementation of the proposed conceptual framework.

It is predicted by using this conceptual framework that the first step is investigating available BIM technology tools in the market with respect to four main tiers; visualisation tier, file format standard and management tier, semantic tier and software tier. Each BIM technological tier drives structural engineering information management towards attaining a specific target (See Figure 7-3). The targets for adopting BIM-based visualisation technology are drawing, rendering and providing reports. The target for adopting BIM-based file format standards is exchanging information with client, local authorities, constructors and other design disciplines. The target for adopting semantic BIM technologies is to gain access to requested information and finally the target of adopting structural engineering software is to analyse and design structural elements. The framework as shown in Figure 7-3 confirms that, some key factors have been examined through research findings are to be strongly and positively correlated with information quality. It is predicted by using the proposed conceptual framework that the second step is evaluation of identified BIM technologies with respect to strong significant factors which are presented in Figure 7-3 by colour coded relations for each dimension of structural engineering information quality. The proposed conceptual framework can guide structural engineers to adopt efficient BIM technologies with respect to enhancing information accuracy, information accessibility and information interoperability.

The second domain of the proposed conceptual framework is BIM workflows. This domain represents the process phase of BIM-based information management in the structural engineering sector. It is predicted by using this conceptual framework that the third step is adopting a BIM workflow for information management or developing their individual organisational BIM workflow. This research recommended structural engineering firms to develop their own BIM framework based on their adopted BIM technologies, their budget and human resources. The proposed conceptual framework (Figure 7-3) represented the key factors in each phase of structural engineering information management (input phase, exchange phase, evaluate phase and publish phase) thorough coloured code with respect to the positive correlation to information accuracy, information accessibility, and information interoperability and information security. The proposed conceptual framework can guide structural engineers to adopt efficient BIM workflows or develop their own company workflow with an aim to enhance information quality.

Finally the third domain of the proposed conceptual framework is the human resource domain. This domain represents BIM-based job requirements and BIM internship as two drivers to prepare structural engineers for implementing BIM selected technologies and workflows. It is recommended strongly in using the proposed conceptual framework that the fourth step is to consider BIM software application skills, knowledge of BIM concepts and understanding of BIM standards during recruitment structural engineers, BIM managers and design managers resources. And also this proposed conceptual framework strongly recommends the conduction of internship programs for junior structural engineers for learning BIM-oriented technologies, knowledge of BIM concepts and BIM standards. It is supported by research findings that BIM-based recruitment and internship in structural engineering companies can significantly contribute to information accessibility, information accuracy and information interoperability.

7.6 Chapter Summary

The proposed conceptual framework has been presented in this chapter, thereby fulfilling the research aim and objectives. All the findings from the literature review, qualitative case studies and quantitative survey have amalgamated, and the key components of the conceptual framework have been discussed in this chapter. Key BIM-oriented options and the influential factors that should be considered while adopting BIM are clearly displayed in the framework. Moreover, the contribution of each factor towards enhancing information quality has been displayed in the conceptual framework. It is believed that the proposed conceptual framework would assist structural engineering organisations enhance the information quality in their organisations. To amend the conceptual framework for further development, a process of refinement and validation was conducted. Six experts with a strong background in structural engineering and BIM implementation were interviewed to evaluate the conceptual framework. These experts established that the proposed conceptual framework was easy to use, was applicable to the structural engineering industry and comprehensively covered factors that were related to the subject. Moreover, they also held the view that this framework would make a significant contribution to both the industry and the existing body of knowledge. The main research findings, limitations of the present research and recommendations for future research are highlighted in the next chapter.

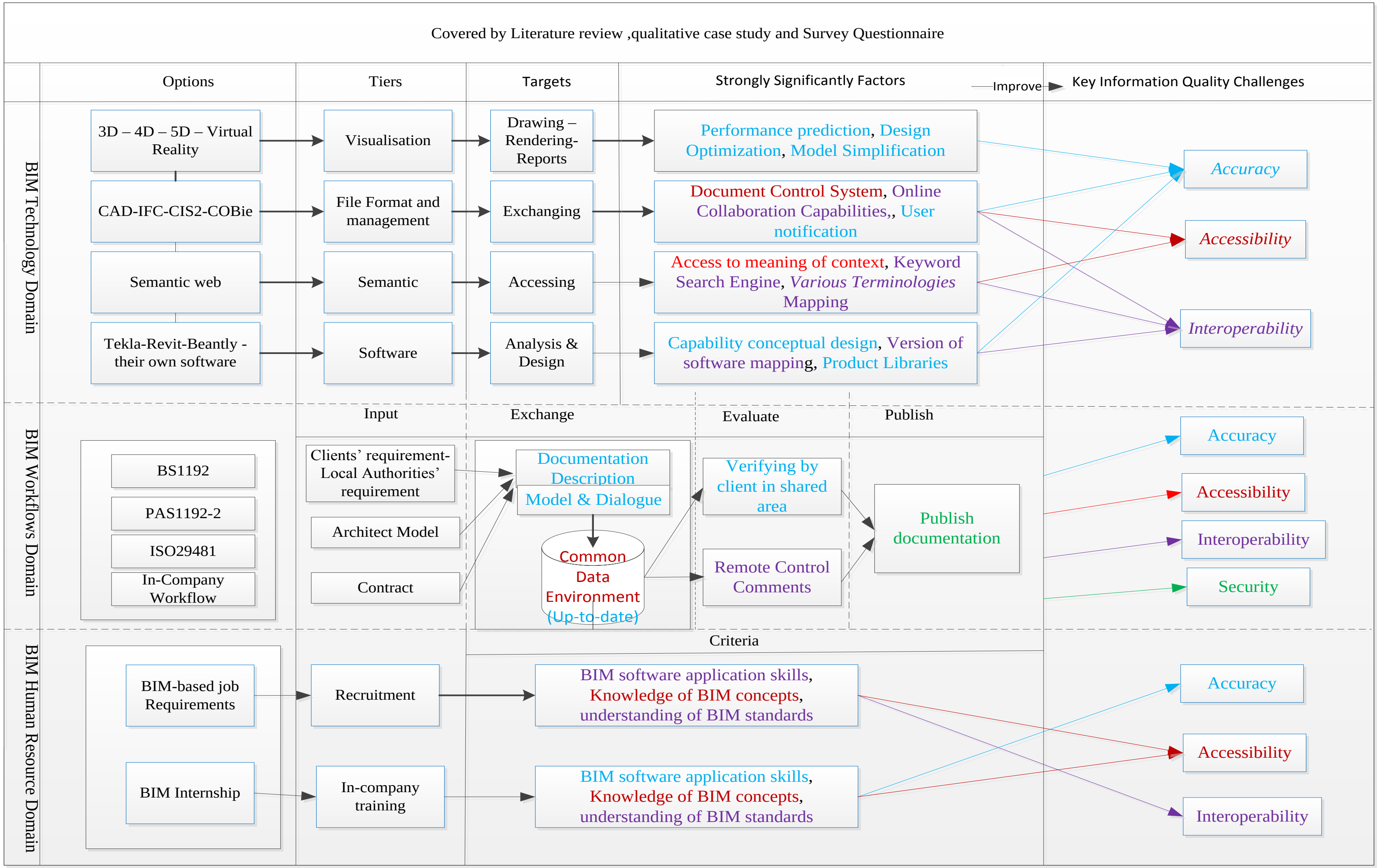


Figure 7-3 Refined Conceptual Framework

CHAPTER 8. CONCLUSION

Conclusions of this research are presented in this final chapter. The key findings of the research are summarised based upon the research objectives that were established for the research. The findings are derived from a review of the literature, two qualitative case studies and a quantitative survey of structural engineering professionals in the UK. The first section of this chapter presents a review of the research aims and objectives that is followed by the contribution to knowledge, limitations of the research and recommendations for future studies in the subsequent sections.

Table 8-1 Research objective achievements

	Literature review	**Case Study**	**Survey**	**Key Finding**
Objective i	✓	✓	✓	Information management challenges
Objective ii	✓	✓	✓	Key criteria in adoption BIM
Objective iii		✓	✓	Relationships between variables
Objective iv	✓	✓	✓	Conceptual Framework

The overall success of the research in achieving the research aims and objectives in reviewed in this section. The aim of this research was to develop a conceptual framework for adopting BIM by structural engineering organisations in the UK in order to enhance the quality of information management. The present research proposes a conceptual framework that elucidates the influence of key BIM factors on the various dimensions of information quality, thereby achieving the aim. Therefore, the following research objectives were formulated to achieve research aim to enhance structural engineering information quality by implementing Building Information Modelling in the UK structural engineering sector.

Objective-One: To develop a comprehensive understanding of key challenges in structural engineering information management within the UK;

An examination of the key information management challenges faced by the structural engineering industry in the UK was the first objective of this research. The initial step of the research process comprised of a review of literature to unearth issues that were of significance to the field of this research. A review of literature in Chapter 2 examined that, key information management challenges in the structural engineering discipline can be categorised as low structural engineering information quality. The construction industry is not satisfied with the quality of design information, specifically, low quality of structural engineering information can lead to catastrophic failures in the construction process. An in-depth study of the information management challenges in the structural engineering disciple was carried out through two different case studies of structural engineering design projects in two large, multidisciplinary engineering and construction organisations in the UK. This was augmented by a quantitative survey of experts with a vast practical experience in structural engineering, design management and BIM implementation disciplines. The core finding was four key information qualities for the structural engineering sector. These four dimensions can be applied into both required structural information and delivered structural engineering information. This research indicates that information management challenges in the structural engineering sector can be explained by information accuracy, information accessibility, and information interoperability and information security.

First of all, accuracy of structural engineering information is very important for success of construction projects. This research indicates that structural engineering organisations require appropriate control of their information to minimise errors in their delivered information. The structural engineering information should be accurate in terms of fewer errors in drawings and calculations, completeness of information and constructability of information in terms of contractors' abilities and projects' requirements. Secondly, access to requested information in requested time is an essential requirement for structural engineers, particularly in the information collection and information reusing stages of structural engineering information management. This research shows that it is very critical for structural engineers to organise information to be structured for efficient retrieval among structural engineering information management system and database. Thirdly, information interoperability is recognised as a key challenge in structural engineering information management. This research indicates that mapping of information between structural engineering applications and external stakeholder's applications is one of the key challenges. A remarkable amount of time is wasted due to interoperability issues and addressing drawing information exchanged or shared with client, local authorities and contractors. It is revealed by this study that different information formats which are not mapped to each other and changing client requirements time to time are the main causes of lack of interoperability in structural engineering firms. Finally, information security is the fourth key challenge faced by the UK-based structural engineering information management sector. Information security does not merely refer to secured access or authorising access to information. It is likewise related to controlling the power of users in manipulating and publishing information, particularly in the detailed design stage.

Although some large multidisciplinary structural and construction organisations in the UK claimed that they implemented level 2 of BIM, the information is not synchronised between their internal and external information management systems. Moreover, unstructured information including dialogue comments during meetings, emails, telephone conversations and video dialogues are not collected and stored appropriately into the structural engineering information database.

Objective-Two: To critically analyse role of BIM to enhance structural engineering information management and the level of BIM implementation in the UK structural engineering discipline;

From the literature review, the dimensions and options of BIM for improving information management in the structural engineering sector were elucidated. The literature was reviewed on technological, workflows and human resource readiness capabilities of BIM in relation to the structural engineering information management sector. A UK was noted to address this gap in knowledge, qualitative case studies and a quantitative survey were carried out in this research to collect perceptions of structural engineering experts, BIM mangers and design managers about the level of BIM implementation in the structural engineering discipline of the AEC industry. Technological contribution of BIM into recent visualisation capabilities, file format standards such as IFC and CIS2, Semantic and ontology engineering information management and software were highlighted in the literature review. This research discussed about recent BIM protocols such as IDM (ISO 20481), PAS 1192 and BS 1192 and also the importance of human resource training and recruitment.

The qualitative case study asked experts involved in two structural design projects in the UK to describe the role of technological tools, process workflows and human resources readiness towards information management in their current projects. To substantiate findings the data was used to design quantitative survey (questionnaire) for larger sample respondents to rate how often they used identified BIM technological, workflows and human resources readiness strategies in their organisations. The findings show that structural engineering organisations in the UK do not utilise technological tools, process workflows and human resources readiness training and recruitment strategies of BIM to the maximum potential. Most of the structural engineering organisations including small, medium and large sizes do not use 4D, 5D and virtual reality for simulation their models. Open file standards such as IFC, COBie and CIS2 are not utilized for exchanging their models. Moreover, in the majority of these organisations, the semantic web is not used to access the meaning of the contexts. Adoption of structural engineering and design packages by most of these organisations is merely based upon existing industry practices and not on BIM criteria. In terms of process workflows, most of the structural engineering organisations do not adopt any of the available BIM workflows for information management. Knowledge and skills related to BIM technological tools, workflows and concepts are influential in the recruitment of structural engineers, however, there is not an efficient strategy to train structural engineers in the company to increase employees' BIM-oriented skills and knowledge. Most of the structural engineering companies in the UK do not utilise the maximum potential due to lack of established guidelines to show them what criteria they need to consider for adoption of BIM options and how those criteria can address their key challenges.

Objective-Three: To examine the relationship between identified key challenges within structural information management and BIM technologies, processes and human readiness dimensions;

The third objective of this research was "To examine the relationship between identified key challenges within structural information management and BIM technologies, workflows and human resources readiness". This objective entailed the investigation of key criteria that need to be considered while adopting various dimensions of BIM to improve information quality in structural engineering organisations. A mixed method approach was found suitable to meet this objective and hence was used to assess these criteria and evaluate their impact on each dimension of information quality. A deep investigation was carried out in the qualitative case study to examine the criteria that need to be considered while choosing BIM based technological tools, workflows and human resource factors for improving the information quality in structural engineering organisations. The quantitative survey that was conducted served to measure the individual contribution of each criterion on the various dimensions of information quality. The third objective is addressed through case studies and survey and synthesis the key themes that are derived from the perceptions of the participants. The key themes of key criteria for the adoption of BIM in structural engineering organisations were discovered by qualitative data analysis of two cases (See chapter 5). The two ongoing structural engineering design projects within UK were studied by understanding perceptions of key stakeholders of structural information management. The key criteria outlines key concerns of structural engineers before adopting BIM technological tools, workflows standard and recruit or train human resources. The quantitative data findings explored the outcomes of each criterion on information quality dimensions in structural engineering discipline (See chapter 6). The findings from objective three in this research lead to the development of the conceptual framework to address the concerns of structural engineers on significant criteria to adopt efficient technological tools, workflow standards and make ready its personnel to enhance quality of information (See chapter 7).

Objective-Four: To develop and validate a conceptual framework for implementing BIM in the UK structural industry to improve information quality management;

To aid structural engineering organisations in adopting BIM, a conceptual framework was developed and has been presented in section 7.3 of chapter seven. A further six interviews were carried out, with leading experts from the industry and academia to validate and further refine this conceptual framework. These experts had several years of experience in research related to BIM implementation in the AEC industry and in the discipline of structural engineering design in the UK. The key concepts elucidated from the interviews and measurement that demonstrated the relationships between the variables sourced from the survey were while developing the conceptual framework. The key criteria that need to be considered while adopting available BIM-oriented options have been highlighted in the conceptual framework and the linkage between these criteria and their contribution to the information quality presented.

There are many BIM-oriented options for structural engineering organisations to adopt in their information management system to enhance their information quality. This research shows that there are three main domains which are technology, process and human resources readiness that can strongly contribute to the quality of information in structural engineering discipline. Within the technology domain the options can be classified into four main tiers which are visualisation, file format and file management, semantic and software tiers.

The BIM technology domain comprises of four options of which the first includes 3D, 4D and 5D virtual realities, that target visualisation. This option is entrusted with drawings and rendering of reports, and impact performance prediction, design optimisation and model simplification and thereby addresses the accuracy aspect of the information quality challenges. Targeting file format and management, the second option comprises of CAD-IFC-CIS2-COBie, and deals with the exchange of information and addresses the document control systems, online collaboration and user notification. Accessibility, interoperability and security aspects of information quality are affected by this option. The semantic web is the third option and targets semantics and deals with information access. The meaning of context, keyword based search engines and mapping of various technologies are influenced by this option, and affects the accessibility and interoperability aspects of the information quality challenges. The fourth is the Tekla-Revit-Beantly option or any other software developed by the organisation and targets the software aspects of BIM technology. Focusing on analysis and design, this option is associated with capability and conceptual design, version of software mapping and product libraries and addresses accuracy and interoperability aspects of information quality challenges. In terms of the BIM workflow domain, there are also four options and these include the various generic workflows that are commercially available such as the BIS1192, PAS 1192-2, ISO29481, and several specific workflows that have been designed and are used by individual organisations. These workflows are similar to each other in terms of functional organisation, and comprise of four functions which are input, exchange, evaluate and publish. Input serves to capture information from all sources, which is then processed by the exchange function to create a common data environment. The evaluate function helps the client verify the data and add comments if any. Finally the publish function helps to get the output data in the required formats. All four key aspects of information challenges such as accuracy, accessibility, interoperability and security are impacted by this domain. The resource readiness domain comprises of two options, Job description based upon BIM requirements and BIM internships and this option targets the recruitment and training processes. Information challenges due to accessibility and interoperability would be addressed by the BIM based recruitment option, whereas the BIM based internship option would help the organisation face challenges arising from accuracy and accessibility issues. Development of the BIM conceptual framework as described would help structural engineering organisations enhance their information quality, and help the organisations survive in a highly competitive AEC environment of the UK.

This research recommended structural engineering organisations across the UK to develop their agenda to adopt BIM based on the proposed conceptual framework in this research (See Figure 7-3). The proposed conceptual framework guides structural engineers to classify BIM adoption into three main domains. Firstly, the proposed conceptual framework recommends that structural engineering firms adopt BIM technological tools based not only on following the industry but also on the outcomes of information quality dimensions. Technological development of BIM tools is progressing on a day to day basis, and this research has covered tools that were available up to 2015, however, the criteria to choose efficient BIM based technology in structural engineering context are presented in this framework. Conceptual framework guides structural engineers to check performance prediction, design optimisation and model simplification of available technology related to visualisation tiers to enhance the level of accuracy of the model. In the course of file format and open standard adoption, many protocols are available for structural engineers such as IFC, CIS2 and COBie. To enhance the accuracy and accessibility of structural information, this research recommends that structural engineers consider on document control system, online collaboration capabilities and user notification. It is recommended that structural engineering organisations use semantic web by considering the capabilities of available webs in terms of access to meaning of context, key word search engine and various terminology mapping to improve accessibility and interoperability of information. The fourth and last tier of BIM technology is adapting software for analysis and design purpose. Many software tools are available in the market for use by structural engineers, and this research recommends that the structural engineering firms look at capabilities of those software in terms of conceptual design, compatibility of software in different versions and richness of product library to increase accuracy and interoperability.

8.1 Contribution to Knowledge

This research through a critical literature review has provided a significant body of knowledge on identifying key information management challenges in the AEC industry and particularly within the structural engineering sector. The key dimensions of the quality of information developed by structural engineering organisations for bidding purposes or for reporting to clients have been identified in this research. Furthermore, the potential of BIM to enhance the level of accuracy, accessibility, interoperability and security in structural engineering documents has been explored. The impact of identifying key BIM tools on the level of quality of structural documents is measured in this study. The findings of this research would hopefully help the UK structural industry have a better understanding of the key BIM tools that would help in improving their documents and assist in taking logical decisions by using BIM tools and standards.

In the present study, the contents of information management challenges in the AEC and structural engineering sector are studied and it is revealed that the four key dimensions of information quality in the UK structural engineering organisations are; information accessibility, information accuracy, information interoperability. This argument has been tested by conducting case studies among structural engineering experts in the UK and information security as the fourth dimension of information quality in structural engineering sector has been investigated.

In spite of the abundance of literature on the in-depth studies on BIM as a method to manage information throughout the life cycle of the building, certain lacunae exist in our knowledge. BIM has been determined as a set of interacting technological, process workflows and organisational culture to maintain the information in all design, construction and asset management projects. However, there is a dearth of literature in classifying key contribution of BIM into quality of information in structural engineering in the UK. This research fills this gap by investigating the key factors in technology, process workflows and organisational training of BIM method to contribute to the information quality in the UK structural engineering organisations. This research proposes a framework for BIM adoption in the UK structural engineering to ensure better information quality.

This research would contribute to existing knowledge by proposing a conceptual framework for adoption of BIM with the purpose of improving the quality of both graphical and non-graphical information. This conceptual framework will serve to outline the relation between the technological aspects, existing protocols of workflow dimensions and the requirements and concerns of experts in the outcomes of structural information in the UK construction industry. Moreover, this framework would be contextualised in terms of the construction body of knowledge and would serve as a reference point for future research in the field of application of BIM in an integrated structural information management system.

8.2 Research Limitations

There is no limit to knowledge and a research is an attempt to gain an understanding of a specific area. Even if the main aims of the research are met and the objectives fulfilled, there would still be scope for improvements; some limitations would always be present. In the present study also there are a few limitations. The lack of previous research linking information quality with BIM adoption forced the researcher to focus on data collected from the interviews and questionnaire to supplement the information gathered from the literature review. Geographic limitations exist in the results as the data for this research was collected from the UK only, and the findings of this study may not be valid at other locations. Finally, time and cost limitations restricted this research to information quality within the structural engineering discipline only with the exclusion of other disciplines of the AEC industry from the scope of this research. The aim of this research due to restricted time and cost of PhD education is limited to develop a conceptual framework to enhance information quality in structural engineering context. Therefore, the applicability of this research in other disciplines such as architectural, building services and facility management has not been investigated.

8.3 Future Research

Several ideas relating to potentially interesting and relevant research issues were encountered during the course of this research, but constraints arising from a lack of time and resources prevented further perusal. Future research can be carried out in pursuance of this study with larger sample size for the interviews or specific case studies that might strengthen the results. Replicating this study with additional qualitative data related to information quality in other disciplines of the AEC industry and comparing the results with that of the present study would serve to validate the findings of this study. A repetition of this study in other geographical locations may serve to both validate this study and ensure applicability beyond national boundaries. Further studies that evaluate the outcome after implementing BIM in structural engineering organisations may serve to validate the conceptual framework proposed in this research.

The future of the AEC industry is still being influenced by the concepts of BIM, and while refining the conceptual framework, some of the experts were of the opinion that BIM ownership can prove to be an important concept that can influence information quality. A beginning has been made with this research, and a strong stance taken to face the challenges related to the ownership of information across the AEC industry. This research underscores the importance of technological factors, workflows and human resource issues in managing information in the AEC industry and in ensuring the ownership of information. Future research can indicate the influence of BIM implementation in information quality.

It is also investigated from this research that dialogue information which is created during meetings between structural engineers and other stakeholders is a very critical issue in structural information management. This kind of information is often missed and structural engineers do not have access to this information after meetings. This issue has a negative influence on information accuracy and accessibility. Future research has this opportunity to provide some solutions to address these issues either through developing technological solutions or through conceptual frameworks or guidelines.

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APPENDIX A – INTERVIEW INVITATION LETTER

Dear Sir or Madam

My name is Mehdi Bavafa. I am a PhD candidate at the School of the Built Environment, University Salford, and Greater Manchester. I am currently undertaking a research into "Enhancing Information Quality through Building Information Modelling Implementation within UK Structural Engineering Organisations" which is supervising by Dr. Zeeshan Aziz. I shall be most pleased if you could confirm your participation in this research through the below contact.

The overall aim of this research is to develop a framework that defines, a through integrated design environment, each phase of the structural engineering process with the client and the architectural agents design system. In recent years, sophisticated technological aids have played key roles in modern construction industry. These aids have effectively replaced paper documents with electronic documents and electronic documents with Building Information Modelling systems. Despite this advent, the construction industry continues to suffer from inaccurate designs. This research identified issues in three different aspects of building design: technologies, process workflows and human resources readiness. This research seeks to explore the challenges in structural engineering information management and contribution of Building Information Modelling to improve identified challenges.

This Interview is part of my doctoral studies. The overall aim of this interview is to find gaps in data exchange between design participants, who are using BIM (Building Information Modelling). The results of this interview will be published as a part of my PhD thesis and possibly in some journal articles. However, the name and information of the individual participants will not be published, and all information collected in the interviews will be stored in secure environment and coded anonymous in all publications. For further clarifications or information about this research, please do not hesitate to contact me via my email or mobile phone number.

Mehdi Bavafa

School of Built Environment

University of Salford

Email: m.bavafa@edu.salford.ac.uk

APENDIX B – PARTICIPANT CONSENT FORM

Title of Project: Enhancing Information Quality through Building Information Modelling Implementation within UK Structural Engineering Organisations

Name of Researcher: Mehdi Bavafa

Contact of Researcher: M.bavafa@edu.salford.ac.uk

School of the Built Environment

The University of Salford

Manchester

M5 4WT

Statements	Please tick where appropriate		
I have read and understood the participant Invitation sheet for the above research and my participation in the research	No	Yes	N/A
I have been given the opportunity to ask relevant questions about the research			
I agree to take part in the research interview			
I understand that taking part in the research interview include tape recording which I agree to			
I understand that information provided by me during the interview will only be kept for the period of this research			
I understand that information provided by me during the interview will be confidential and will not be disclosed to people outside this research			
I understand that my participation in this research is voluntary, I can withdraw from this research at any time and I do not have to give any reason(s), for why I no longer want to take part in this research and any information I have provided shall accordingly be destroyed immediately			
I hereby agree to take part in this research			

Name of Participant:……………Date……………Signature:…………………………

Name of Researcher:……………Date……………Signature:……………………….

Research Supervisor

Dr. Zeeshan Aziz

School of the Built Environment

The University of Salford

Manchester

M5 4WT

APPENDIX C - SEMI-STRUCTURED INTERVIEW QUESTIONS

A- General Part

1- How many years of experience have you in structural engineering?

2- How would you describe the overall goals of your organization?

3- What are the activities and services of your organisation?

4- What are the challenges in terms of managing information?

5- How are decisions made in your organisation? Is any IT system included in this process?

6- How would you describe your clients?

7- Please describe about your main projects in recent 5 years?

8- What are the key strategic methods for choosing software in your organisation?

B- Technical Part

1- What kind of data does your organisation require for creating the structural model in conceptual, tendering and detailed stages?

2- How and what data do you obtain from other design participants, and who are they?

3- How do you share those data in your internal engineering team?

4- What software package(s) do you use for analysis and design and why?

5- Are your analysis and design packages separate applications? If yes, how do you share the data between them?

6- What kind of technical problems have you faced during exchanging data with other participants?

7- How do you collaborate with client, architect and building services engineers? How well do you understand their requirements and data needs?

8- Please describe the level of details of your models in each phase of design?

9- How do you obtain feedback about your models from other participants?

10- How do you evaluate your models in terms of client’s requirements, standard codes and constructability?

11- What are your output documents and data?

12- How do you exchange your output with contractors?

APENDIX D – QUESTIONNAIRE INVITATION LETTER

Dear Sir, Madam

My name is Mehdi Bavafa a PhD candidate at the School of the Built Environment, University Salford, Greater Manchester. I am currently undertaking a research into enhancing information quality.

The aim of this research is to propose a framework is to develop a conceptual framework for the adoption of BIM to enhance the quality of information management systems in structural engineering organisations of the UK. In this regard, I have developed a set of questionnaire questions to solicit your organisation's views about your understanding of information management challenges and contributions of BIM into identified challenges. This questionnaire designed to take maximum of half an hour to complete and highly considered as an important contribution to this research.

The below link is a questionnaire as part of PhD research data collection in university of Salford in the UK. This questionnaire is targeting structural engineers, BIM managers, BIM specialists, design managers or researchers who have experience working in structural engineering department or structural engineering firms. I shall be most pleased if you could confirm your participation in this research through the below contact. Your response within two months of receipt of this letter is most appreciated. I would like to inform you that I have taken all the necessary steps to protect the content of this questionnaire and will be kept confidential and be used for the purposes of this research. However, you can withdraw your participation at any time you wish to do. For further clarifications or information about this research, please do not hesitate to contact me via my email or School of the Built Environment, University of Salford, Manchester, M5 4WT who is supervising this research.

Questionnaire Online Link:
https://www.surveymonkey.com/survey-closed/?sm=nteHhjbIjkK1oqfy5gRJpTNsogGW13BEgtxQy%2bRFTcsFRvezH5htu9BOGuUZ%2bGH7dU83YJ%2fQoZ%2b3cD5eAohn0w%3d%3d

Yours sincerely,

Mehdi Bavafa

School of Built Environment

University of Salford

Email: m.bavafa@edu.salford.ac.uk

APPENDIX E – QUESTIONNAIRE QUESTIONS

Part 1- Participants demographic

1. Please specify the years of experience that you have got in structural engineering industry?

- Please specify the years of experience that you have got in structural engineering industry? 0-5 years
- 5-10 years
- 10-15 years
- more than 15 years

2. Please describe your current role in your organisation?

- Please describe your current role in your organisation? Junior Structural engineer
- senior structural engineer
- BIM manager
- Design manager
- Researcher

Other (please specify)

3. Please specify the type of your organisation?

- Structural design
- Multidisciplinary engineering consultancy
- Architectural and engineering consultancy
- AEC multidisciplinary (design & construction)

Other (please specify)

4. Please specify the size of your organisation

- Small (Less than 50 employees)
- medium (between 50 to 100 employees)
- Large (more than 100 employees)

5. Please specify number of structural engineers involved in your organisation?

- Less than 10
- between 10 - 20
- between 20 - 30
- more than 30

6. Is any portion of design work outsourced to third party designers?

- Yes
- No

Part 2- Information Management Challenges

7. Please specify the most critical information management challenges in your organisation?

	Not challenge at all	No challenge	Neutral	Critical challenge	Very critical challenge
Different format of data	○	○	○	○	○
Data exchange between different applications	○	○	○	○	○
Unavailable information in requested time	○	○	○	○	○
Lack of information management standard practice	○	○	○	○	○
Inefficient Tacit knowledge repository	○	○	○	○	○

	Not challenge at all	No challenge	Neutral	Critical challenge	Very critical challenge
Lack of internal communication	○	○	○	○	○
Lack of external communication	○	○	○	○	○
Information security	○	○	○	○	○
Tracking information	○	○	○	○	○
Information timeline	○	○	○	○	○
Information accuracy	○	○	○	○	○

Other (please specify

Part3- BIM Adoption in Structural engineering discipline

8- How often in your organisation these following tools are used?

	Not at all	Rarely	Sometimes	Often	Very Often
2D CAD drawing	○	○	○	○	○

3D CAD model					
4D model with cost scheduling					
5D model with cost and time scheduling					
Virtual reality (augmented reality)					
IFC					
CIS2					
COBie					
DWG file					
PDF file					
Text file					
Spread sheet					
JPEG file (Image file)					

Tekla structure software	○	○	○	○	○
Revit structure Software	○	○	○	○	○
Beantly structure Software	○	○	○	○	○
Your own company software	○	○	○	○	○
Intelligent website for searching context (semantic web)	○	○	○	○	○
Sharing documents through web channel	○	○	○	○	○
Sharing documents through Cloud	○	○	○	○	○

Other (please specify)

Other (please specify)

9. Please describe how satisfied are you about following outcomes by using available tools (which are mentioned in Q8) in your organisation?

	Not satisfied at all	Not satisfied	Neutral	Satisfied	very Satisfied
Performance prediction	○	○	○	○	○

	Not satisfied at all	Not satisfied	Neutral	Satisfied	very Satisfied
Design optimization (validating material and size of components)	○	○	○	○	○
User notification	○	○	○	○	○
Simplify access	○	○	○	○	○
Third party secured access	○	○	○	○	○
Integrated search function	○	○	○	○	○
Information be Updated regularly in your system	○	○	○	○	○
Various terminologies mapping	○	○	○	○	○
Keyword search	○	○	○	○	○
Access to meaning of context	○	○	○	○	○
capability for conceptual design	○	○	○	○	○

	Not satisfied at all	Not satisfied	Neutral	Satisfied	very Satisfied
Version of the software	○	○	○	○	○
Online collaboration capabilities	○	○	○	○	○
Product libraries contents	○	○	○	○	○

Other (please specify)

10. What kind of information management standard has been using in your organisation? If you use your own standard please describe it in more details.

- ○ PAS 1192-2
- ○ PAS 1192-3
- ○ ISO 29481 (IDM)
- ○ You do not use any standard
- ○ Other (please specify)

Other (please specify)

11. Please describe how satisfied are you about following outcomes by using mentioned information management standards in Q10?

	Not satisfied at all	Not satisfied	Neutral	Satisfied	Very Satisfied
Access to technical context at any time any where	○	○	○	○	○
Access to general context at any time any where	○	○	○	○	○
Catching and store the contents from meetings into electronic documents	○	○	○	○	○
Document control system	○	○	○	○	○
Matching the final technical documents with client's requirements	○	○	○	○	○
Remote electronic comment on documents	○	○	○	○	○
Clear description of documents in your electronic data warehouse	○	○	○	○	○

Other (please specify)

12. What are your organisation BIM-based priorities for recruitment structural engineers?

	Not important at all	Not important	Neutral	Important	Strongly important
BIM software application skills	○	○	○	○	○
Knowledge of BIM concepts	○	○	○	○	○
Understanding of BIM standards	○	○	○	○	○

Other (please specify)

13. What level of training is being provided in use of BIM in your organisation for structural engineers?

	Not providing at all	Providing Very general	Providing general	Providing	Providing in details
BIM software application skills	○	○	○	○	○
Knowledge of BIM concepts	○	○	○	○	○

	Not providing at all	Providing general	Very Providing general	Providing	Providing in details
Understanding of BIM standards	○	○	○	○	○

Other (please specify)

14. Please describe how satisfied are you about information quality in your organisation?

	Not satisfied at all	Not satisfied	Neutral	Satisfied	Strongly satisfied
Information accuracy	○	○	○	○	○
Information accessibility	○	○	○	○	○
Information interoperability	○	○	○	○	○
Information security	○	○	○	○	○

Other (please specify)

15. Please Specify your final comments or any other information based on your knowledge or experience that you think would help this research?

APENDIX F – ETHICAL APPROVAL

Academic Audit and Governance Committee

College of Science and Technology Research Ethics Panel

(CST)

University of Salford MANCHESTER

To **Mehdi Bavafa and Prof Arto Kiviniemi**

cc: **Prof Mike Kagioglou, Head of School of SOBE**

From **Nathalie Audren Howarth**, **College Research Support Officer**

Date 8th May 2012

Subject: **Approval of your Project by CST**

Project Title: Accurate Structural Design Through the BIM

REP Reference: **CST 13/58**

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

Nathalie Audren Howarth

College Research Support Officer

APPENDIX G - LIST OF PUBLICATIONS

Bavafa, M. Kiviniemi, A. and Weekes, L. (2012). Optimised Strategy by Utilising BIM and Set-based Design : Reinforced Concrete Slabs. *Proceeding of the 29th International Conference on Application of IT in the AEC Industry, CIB W078 2012*, October 2012, Beirut, Lebanon.

Bavafa,M. Kiviniemi,A. (2013). Interoperability in Semi-Intelligent Civil Engineering Agent. In: *CIB W078 2013 Conference,* August 2013, Beijing, China

Bavafa, M. (2014). Towards Interoperability in the UK Construction Design Industry. In: *Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering*, June 2014, Orlando, Florida.