A Conceptual Framework for Sharing Knowledge and Information between Facility Management/Operations and Building Design Teams

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DEDICATION

This work is dedicated to my mother, **Linda Anne Long**, and to the memory of my late father, **James Ernest Long II**, who taught me the importance and value of education. And that it is never too late in your to life educate yourself further.

It is also dedicated to my two sons: **Preston James Long** and **Owen Fraser Long**, who had to share their father with this work for far too many weekends and evenings. My hope is that this work will help them see the importance of one's education, even if it means missing out on more backyard soccer games than I dare count.

DECLARATION

This thesis is submitted to the University of Salford, United Kingdom, per its rules and regulations for the award of a PhD degree by research.

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 or qualification of this, or any other university or institution of learning. To the best of the researcher's knowledge, this works contains no material previously published or written by another person except where duly referenced and acknowledged.

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Paul W Long

LIST OF ABBREVIATIONS

AE	architecture and engineering
AEC	architecture, engineering, and construction
AECFM	architecture, engineering, construction, and facility management
AECO	architecture, engineering, construction, and operations
AE-Design	architecture and engineering design
AHP	analytic hierarchy process
AIA	American Institute of Architects
AIM	asset information model
BCE	before common era
BIFM	British Institute of Facility Management
BIM	building information modelling
BMS	building management system
BOK	body of knowledge
BPE	building performance evaluation
BPM	building product model
BPR	business process re-engineering
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British standard
CABE	Commission for Architecture and the Built Environment
CAD	computer-aided design
CAFM	computer-aided facility management system
CBA	choosing by advantages
CIC	Construction Industry Council
CIFE	Centre for Integrated Facility Engineering
COBI	construction operations building information exchange
COPRAS	complex proportional assessment
DC	design and construction
DDSS	design decision support system
DDST	design decision support tool
DM	decision model
DMAIC	define, measure, analyse, improve, and control
DQI	design quality index
DRC	design rationale capture
DSR	design science research
DSS	decision support system
FM	facility management
FM/O	facility management and operations
FMs	facility managers
IFC	industry foundation class
IFMA	International Facility Management Association
IoT	internet of things
IPD	integrated project delivery
IS	information systems
ISO	International Organisation for Standardisation
IT	information technology
JITKM	just-in-time knowledge management

KM	knowledge management
LEED	Leadership in Energy and Environmental Design
MAUT	multi-attribute utility theory
MCDA	multi-criteria decision analysis
MCDM	multi-criteria decision making
NBS	national building specification
NGO	nongovernmental organisations
NPS	National Park Service
OM	operation and maintenance
PAS	publicly available specification
PM	project management
PMI	project management institute
POE	post-occupancy evaluation
PROMETHEE	preference ranking organisation method for enrichment
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
TOPSIS	technique for order of preference by similarity to ideal solution
TVD	target value design
UK	United Kingdom
US	United States
USFS	United States Forest Service

ABSTRACT

It is generally accepted that decisions made in early design phases significantly impact the quality of a built project. However, much of the information necessary to assess the validity of early design decisions is not available until later in a project's lifecycle. The impact of early design decisions on project quality suggests that accurate, relevant, and timely information is important at the earliest design phases to improve a designer's ability to make well-informed design decisions. This thesis proposes that because of their active engagement with the built environment, facility managers (FMs) have unique insights that strategically position them to play an essential role in the early phases of building design by providing knowledge and feedback from buildings in use.

Because early design sets the foundation for linking strategic and technical decisions, the most significant opportunities for improving overall project results are at the beginning of a project. Facility management and operations (FM/O) involvement in early architecture and engineering (AE) design phases makes it possible to incorporate construction and FM related knowledge into design decisions. This involvement may lead to buildings that are better suited to owners' needs, more attractive, easier to maintain, more cost-effective, and better at addressing occupant needs. However, while research suggests design teams and design processes will increasingly become integrated and multi-disciplinary as advanced automated construction and information management systems become standard, obstacles persist, limiting the sharing of information and knowledge between FM/O and AE-design teams.

This thesis evaluates and develops mechanisms and procedures to enhance the sharing of information and knowledge between FM and AE-design teams. With a focus on built environment industries in the midwestern region of the United States (US), data is collected from AE and FM professionals to support the development of a framework that offers solutions for enhancing information sharing between FM/O and AE-design. The developed framework is presented as a design decision support system (DDSS) made up of conceptual design decision support tools (DDSTs). The thesis describes a mixed method, design science research (DSR) strategy, used to develop the conceptual DDSS framework and DDSTs.

1. INTRODUCTION

1.1 Chapter Introduction

Building design and facility management (FM) are typically viewed as distinct disciplines; the former involved at the commencement of a project's life cycle, and the latter engaged during post-occupancy (Jawdeh, Abudul-Malak, & Wood, 2010). Despite this separation, the importance of integrating operational knowledge and data with design is recognised as a means for improving building design decisions (Fatayer, Hassanain, Abdallah, & Al-Hammad, 2019; Kalantari, Shepley, Rybkowski, & Bryant, 2017; Meng, 2013).

Research suggests it is possible to improve design decisions, and subsequent building operations, by integrating the advice of non-design specialists as early in the design process as possible. Applying FM expertise to early design decisions helps address multiple post-occupancy problems, including a lack of operability, maintainability, and serviceability (Arditi & Nawakorawit, 1999; Bröchner, 2003; Erdener, 2003; Fatayer et al., 2019; Jaunzens, Warriner, Garner, & Waterman, 2001; Liu & Issa, 2016; Meng, 2013; Weeks & Leite, 2021). According to Jaunzens et al. (2001), FM involvement in early design decisions also promotes buildings that are better suited to owners' needs; more attractive; easier to commission and maintain; easier to manage; more cost-effective to operate and construct; and better address occupant needs.

1.2 Research Background

The building design process consists of a range of project phases that work from broad to specific. In the United Kingdom (UK), these phases are defined by the Royal Institute of British Architects (RIBA) Plan of Work as 0) Strategic Definition, 1) Preparation and Briefing, 2) Concept Design, 3) Spatial Coordination, 4) Technical Design, 5) Manufacturing and Construction, 6) Handover, and 7) Use (Sinclair, 2020). In the United States (US), the phases are defined by the American Institute of Architects (AIA) as 1) Pre-Design, 2) Site Analysis, 3) Schematic Design, 4) Design Development, 5) Construction Documents, 6) Bidding or Negotiation, 7) Construction Contract Administration, and 8) Post-Construction Services (Hayes, 2014).

While slight differences exist between the AIA and RIBA conceptualisations of the architecture and engineering (AE) building design process, both include the preparation of an initial design based on client requirements and budget constraints. The initial design is then developed into detailed solutions through a series of sequential phases that ultimately lead to construction and occupancy. As a project proceeds through this process, the design becomes more advanced, and changes introduced in later design phases require modification of decisions taken in previous phases (Jawdeh et al., 2010). This characteristic reinforces the importance of early design decisions. Because each design phase builds on prior phases, errors early in the design process have the potential to multiply or be amplified as each new decision is based on a previous one (Kiviniemi & Fischer, 2004).

Within these building design processes, it is therefore generally accepted that due to the far-reaching effects early decisions have on the functionality, operation, and maintenance of built assets, decisions made in early design phases have a significant impact on the quality of a built project (Figure 1.1) (Boge, Salaj, Bjørberg, & Larssen, 2018; Kalantari, Shepley, Rybkowski, & Bryant, 2017a; Kalantari et al., 2017; Kerzner & Kerzner, 2017; Tucker & Masuri, 2016).

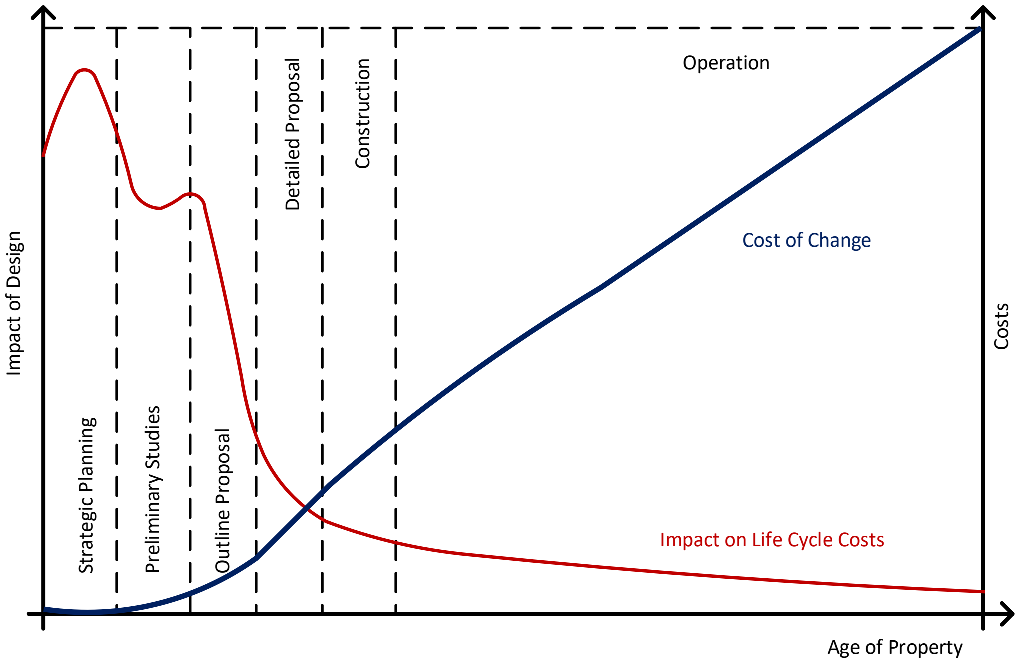


Figure 1.1: Life-cycle costing of real-estate
(Meslec & Ashworth, 2017)

Jaunzens et al. (2001, p. 10) document the long-term impact of early design decisions and find "up to 90% of the cost of running, repairing, and maintaining a building is determined at the design stage." While the exact percentages and ratios of the costs of design, construction, operations, and maintenance, have been debated by researchers such as Hughes, Ancell, Gruneberg, and Hirst (2004) and Ive (2006), it is generally recognised that it is in the early design phases where a majority of the decisions are made that have significant implications on the final cost of a building's lifecycle (Schade, Olofsson, & Schreyer, 2011).

However, despite the importance of early design decisions, knowledge is limited at the beginning of a project, and much of the information necessary to validate and inform early design decisions is not generated until later in a project's life cycle (Ipsen, Pizzol, Birkved, & Amor, 2021). Furthermore, according to the National Institute of Standards and Technology (NIST), "Owners and other stakeholders in the facility life cycle tend to make decisions based on the range of information available to them. Thus, inaccurate or poorly defined information impedes their ability to make sound economic decisions" (GCR, 2004, pp. 1-23).

The lack of knowledge available at the beginning of the design process, when decisions have the most impact, makes it challenging to evaluate design decisions before the information necessary for assessment is available (Roberts, Allen, & Coley, 2020). In addition, when the information required to evaluate design decisions is available, the ability to revise such decisions is limited, which suggests access to accurate, relevant, and timely information is valuable if one seeks to improve design decision-making processes (Figure 1.2).

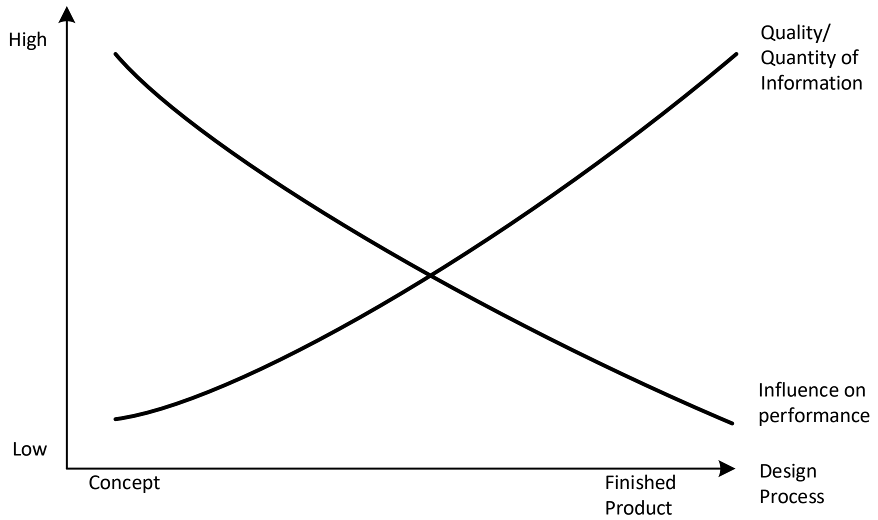


Figure 1.2: Impact of design decisions across building design and construction process
(Adopted from Roberts et al., 2020)

Dunston and Williamson (1999) reinforce this relationship in their findings that the most benefit from design input for the least cost is found at the 30% project review stage. While, on the other hand, at the 90% project review stage the least benefit is received for the greatest cost when integrating new design input. NIST similarly finds that changes made early in the design and construction process have a significant overall impact with relatively low associated costs. Meanwhile, the further a project develops, the more difficult and expensive changes are to make. Furthermore, according to NIST, the ability to effectively integrate and share information across design, construction, and operational stages of a building's lifecycle is an effective method to reduce industry losses and add value to industry stakeholders (GCR, 2004).

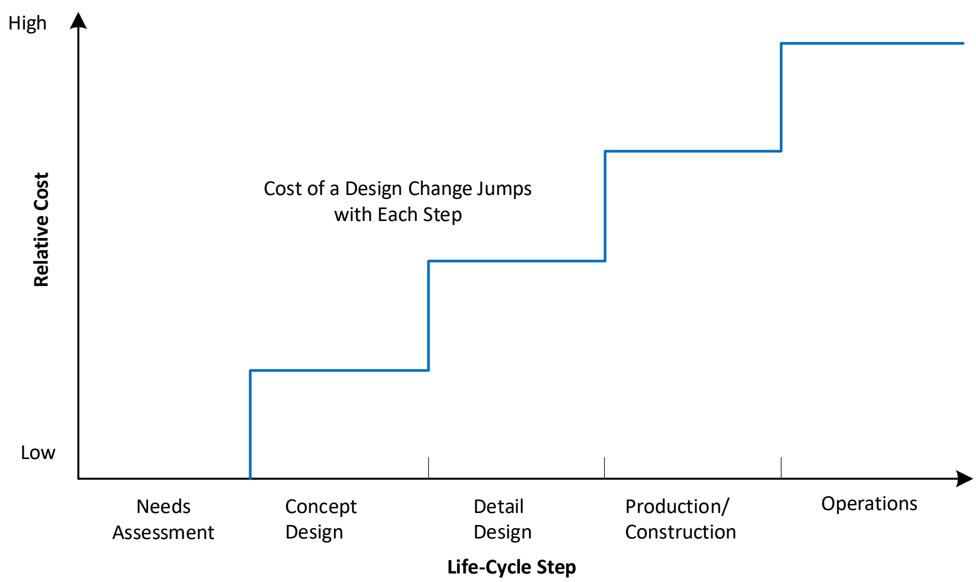


Figure 1.3: Cost impact of changing facility design at differing stages in the facility life cycle (adapted from LMI as cited in GCR, 2004)

1.2.1 Facility Management Overview and Definition

Facility management can be viewed as a historical practice that reaches as far back as the ancient Romans (Bröchner, 2010). However, while the practice of FM existed in ancient times, the use of the term facility management did not develop until the 1970s (Best, Langston, & Valence, 2018). According to Nor, Mohammed, and Alias (2014, p. 9), modern FM emerged from work in North America "to describe the developing field of study into the design and management of workplaces and their impact on the business organisations that occupied them." The development of the FM profession has also been attributed to the increased complexity of buildings and their associated costs, increased global business competition, and increased occupant expectations (Becker & Steele, 1990; Nor et al., 2014).

Modern facility management is a multi-faceted profession that integrates the people, process, place, and technology within the management of an organisation (BIFM, n.d.; IFMA, n.d.-c). E. Teicholz (2001, p. 21) describes FM as a “multidisciplinary or trans-disciplinary” profession that deals with knowledge from diverse disciplines such as engineering, architecture, accounting, finance, management, and the behavioural sciences. The International Facility Management Association (IFMA) describes FM as “a profession that encompasses multiple disciplines to ensure the functionality of the built environment by integrating people, place, process, and technology” (Figure 1.4) (IFMA, n.d.-c). K. Alexander (2013, p. 7) describes the domain of FM as encapsulating the application of “techniques to improve quality, add value and reduce the risks involved in occupying buildings and delivering reliable support services.” The British Institute of Facilities Management (BIFM, n.d.) describes FM as encompassing “multidisciplinary activities within the built environment and the management of their impact upon people and the workplace.” They additionally see FM as “vital to the success of any organisation” due to FM’s responsibility to provide and maintain a range of services such as property and space management, communications, infrastructure and building maintenance, administration, and contract management. Facility Management is thus concerned with more than the operation and maintenance (OM) of a building; it is also concerned with strategic planning and user experiences.

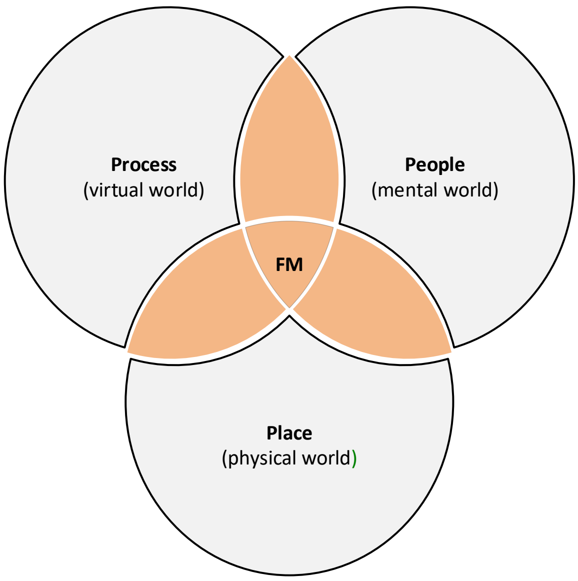


Figure 1.4: FM domains
(adapted from Finch & Zhang, 2013)

According to Nor et al. (2014), there is a common vision and mission within the range of FM definitions (Table 1.1 and Table 1.2). Citing Hakim et al., Nor et al. (2014, p. 6) find in modern depictions of FM the fundamental concept that "workspace environment and activities… [can be] defined, measured, analysed, improved and controlled to sustain continuous longevity and profitable growth." The identification by Nor et al. of these fundamental aspects of FM, particularly that effective FM is tied to the analysis and improvement of workspace environments, suggest a direct connection between the role of FM and facility design. Mohammed and Hassanain (2010, p. 84) additionally suggest that while the "role of facilities management should not be confused with that of facility design," the nature of FM affords it the "potential to contribute to the design stage by providing a useful feedback from the knowledge acquired during the operational phase of the facility."

Table 1.1: Definitions of FM from various professional and standards organisations

Select Industry Definitions of Facility Management	
IFMA (IFMA, n.d.-c)	The practice of coordinating the physical workplace with the people and work of the organisation; integrates the principles of business administration, architecture, and the behavioural and engineering sciences.
RICS Guidance (RICS, 2013)	The effective management of place and space, integrating an organisation's support infrastructure to deliver services to staff and customers at best value whilst enhancing overall organisational performance.
BIFM	Adopts ISO definition below.
Estates (1996)	The practice of coordinating the physical workplace with the people and work of an organisation; integrates the principles of business administration, architecture, and behavioural and engineering science.
ISO 41011:2017 (ISO, 2017)	An organisational function which integrates people, place, and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business.
European Standard (Standard, 2006)	Integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities.

Table 1.2: Various academic definitions of FM

Select Academic Definitions of Facility Management (adapted from Tay & Ooi (2001)	
Author	**Definition of FM**
Becker and Steele (1990)*	FM is responsible for coordinating all efforts related to planning, designing, and managing buildings and their systems, equipment, and furniture to enhance the organisation's ability to compete successfully in a rapidly changing world.
Nourse (1990)	FM is seldom aware of the overall corporate strategic planning and does not have a bottom-line emphasis.
Moore and Finch (2004, p. 259)	The development, coordination, and management of all of the non-core specialist services of an organisation, together with the buildings and their systems, plant, IT equipment, fittings, and furnishings, with the overall aim of assisting any given organisation in achieving its strategic objectives.
K. Alexander (2013)	The scope of the discipline covers all aspects of property, space, environmental control, health and safety, and support services.
Shiem-Shin Then (1999)	The practice of FM is concerned with the delivery of the enabling workplace environment – the optimum functional space that supports the business processes and human resources.
Hinks and McNay (1999)	… common interpretations of the FM remit: maintenance management; space management and accommodation standards; project management for new-build and alterations; the general premises management of the building stock; and the administration of associated support services.
Varcoe (2000)	… a focus on the management and delivery of the business "outputs" of both of these entities [the real estate and construction industry]; namely the productive use of building assets as workplaces.
Nutt (2000)	The primary function of FM is resource management, at strategic and operational levels of support. Generic types of resource management central to the FM function are the management of financial resources, physical resources, human resources, and the management of resources of information and knowledge.
*Becker and Steele are the only definitions to directly recognise the potential for FM to be involved in design.	

1.2.2 Working Definition of Facility Management

As the context of this thesis is primarily focused on architecture, engineering, construction, and facility management (AECFM) industries in the United States (see Section 1.5), the thesis adopts the definition of FM provided by the International Facility Management Association (IFMA) – the primary professional FM organisation in the US.

IFMA (n.d.-c) defines FM as:

> The practice of coordinating the physical workplace with the people and work of the organisation; integrates the principles of business administration, architecture, and the behavioural and engineering sciences.

IFMA further identifies 11 core competencies of FM (Table 1.3). These competencies clarify IFMA's view of what constitutes FM and help establish IFMA's understanding of the broad nature of the discipline. From this definition and the associated core competencies, professional definitions of FM can be understood as the overall coordination of a facility's operation to make an organisation more effective at what it does (Micromain, 2017). FM is focused on synchronously integrating all facets of management at the corporate level to ensure continuous productivity and sustainable business growth (Nor et al., 2014).

Table 1.3: IFMA core competencies

IFMA Core Competencies of Facility Management (IFMA, n.d.-a) (See Appendix A for elaboration on each of the core competencies.)	
Definition of FM: The practice of coordinating the physical workplace with the people and work of the organisation; integrates the principles of business administration, architecture, and the behavioural and engineering sciences.	
1.	Communication
2.	Emergency Preparedness and Business Continuity
3.	Environmental Stewardship and Sustainability
4.	Finance and Business
5.	Human Factors
6.	Leadership and Strategy
7.	Operations and Maintenance
8.	Project Management
9.	Quality
10.	Real Estate and Property Management
11.	Technology

1.2.3 Facility Management and Building Performance

As noted previously, facility management can be understood as multi-faceted in nature; however, two fundamental aspects of FM are the operation and maintenance (OM) of a built asset, and the management of activities and events which take place within a built asset (Chotipanich, 2004; Nor et al., 2014; Siew, 2015). The latter may also be thought of as the event management of user activities and experiences within a facility. Operational maintenance activities relate to routine support functions to maintain or preserve a facility, add value to physical resources, and to maintain a safe environment for organisational activities. Whereas management functions can be seen as both tactical and strategic, such as specific short-term management operations, or long term strategic planning (Islam, Mohamed, Bjørberg, Misnan, & Yusof, 2017; Kamaruzzaman, Myeda, Zawawi, & Ramli, 2018). Facility management can, therefore, be seen as both OM and event management and includes a broad range of activities and services utilised to ensure a built asset meets its users' needs and fulfils the functions for which it was designed (Sapp, 2017).

Ensuring a facility meets the needs for which it was designed and constructed is increasingly difficult as modern buildings are more complex, costly, and designed to meet and maintain higher standards than in the past (Chew, Tan, & Kang, 2004; Jensen, 2009, 2012; Mohammed & Hassanain, 2010; Tucker & Masuri, 2016). It has been shown there is often a gap between the expected and actual performance and functionality of a newly built facility (Mills, 2011; Ornetzeder, Wicher, & Suschek-Berger, 2016). Building owners, facility managers, and users often experience performance gaps in expected energy use; lack of functionality; poor indoor climate; and difficulty in facility operation, maintenance, serviceability, and cleaning (Fatayer et al., 2019; Jensen, 2012; Rasmussen & Jensen, 2020).

According to (Rasmussen, 2020), these reduced performance gaps often persists until changes can be implemented during operation, although some deficiencies will likely be permanent. Rasmussen further suggests building performance gaps have a negative impact on the economy, environment, quality of life, and productivity of a building's occupants. As facility managers are often blamed for these performance gaps, even when they originate in design (Kalantari et al., 2017), it suggests FMs have an interest in facilitating better design. Furthermore, FM has access to the data, information, and knowledge needed for FM to be able to contribute to design. As a result, FM involvement in design is increasingly seen as vital to the well-being and success of building occupants (Hansen & Damgaard 2012 Chodasova, 2004; Erdener, 2003; Jensen, 2012; Rasmussen, Jensen, Nielsen, & Kristiansen, 2019; Tucker & Masuri, 2016; Way & Bordass, 2005).

As expectations for building performance increase, and as performance gaps continue to persist, the influence of early design decisions become more critical than ever. This is due, in part, to the fact that the effects of early design decisions have been shown to have far-reaching impacts on the functionality, operation, and maintenance of built assets (Chodasova, 2004; Grimshaw & Keeffe, 1993; Jensen, 2012; Rasmussen et al., 2019; Tucker & Masuri, 2016; Way & Bordass, 2005). Subsequently, integrating FM knowledge during design may present a remedy to bridge building performance gaps and help ensure a facility fulfils its design intent (Jensen, 2012; Rasmussen et al., 2019; Way & Bordass, 2005).

1.2.4 Knowledge Transfer from Facility Management to Design

Knowledge transfer from FM to design to improve design decisions is not a new idea (Jensen, 2009). An awareness of the value FM brings to the design process has been around at least since the 1960s. Bröchner (1996) references experiments undertaken in Sweden since the 1960s by the National Swedish Institute for Building Research, which sought to facilitate feedback from FM to design; however, Bröchner finds results from these experiments were unsatisfactory. Kalantari et al. (2017) further find the formal and systematic investigation of collaboration between designers and FM was not considered a factor in architecture until the late 1990s. In the period since, several researchers have investigated opportunities for FM knowledge integration into the design process such as Fatayer et al. (2019); Kalantari et al. (2017a); Kalantari et al. (2017); Liu and Issa (2016); Meng (2013); and Weeks and Leite (2021) (see Chapter 2, Section 2.4 for a more complete discussion).

In an early study to investigate FM knowledge integration in design, the British Institute of Facilities Management (BIFM), working with the Building Research Establishment (BRE), commissioned a report to research the relationship between FM and design teams (Jaunzens et al., 2001). The report sought to “encourage the greater involvement of building facilities professionals in the building design process…”; and was structured to examine why facility managers (FMs) should be more involved in the design process, why they are often excluded from it, and to make suggestions for when they should be involved. The report affirmed the usefulness of collaboration between FM and designers but recognised significant barriers to such collaboration. According to Jaunzens et al., the FM "profession has the prime responsibility for managing buildings – both their facilities and their services…," and given the increased sophistication of buildings and cost associated with facility operation and services, it is surprising and "increasingly unacceptable" that the FM profession is "seldom recognised as having a key role in ensuring that the [FM] requirements are addressed at the design stage"(Jaunzens et al., 2001, p. iv). The work by Jaunzens et al. suggests that FM expertise can be vital to design teams and should be considered across multiple design phases.

1.2.5 Benefits of Facility Management – Design Engagement

Sharing FM knowledge with AE-design has been identified as valuable for a variety of reasons, and other researchers have reached similar conclusions to those found in Jaunzens et al.'s work and suggest significant operational inefficiencies and building maintenance problems may be reduced through better communication between designers and FMs (Fatayer et al., 2019; Kalantari et al., 2017a; Weeks & Leite, 2021).

According to Chew, Conejos, and Asmone (2017, p. 50), "Researchers have emphasised the main causes that lead to building operations and maintenance problems are faulty design and maintenance-related defects." Mohammed and Hassanain (2010) similarly find that operational difficulties are often caused by design faults rather than faults in construction. In addition, Seeley (1987) notes a study undertaken by the Building Research Establishment (BRE) found that 50% of building failures and defects originated in faulty design (see also Chong & Low, 2006). According to Rasmussen et al. (2019) an additional benefit is that changes are more easily made during design, and once a building is in operation, some changes are impossible to implement. Mohammed and Hassanain (2010, p. 85) affirm this view by suggesting that due to the difficulty in altering a facility during the operational phase of its life cycle, it is important to "design for adaptability by considering the probable alteration from the early stages of the design…." They contend that this is difficult to accomplish without FM input.

Other researchers maintain similar conclusions (Table 1.4). Bröchner (1996), Arditi and Nawakorawit (1999), Kalantari et al. (2017), Fatayer et al. (2019), and Weeks and Leite (2021) suggest operational inefficiencies and building maintenance problems can be reduced through better communication between design and FM. Islam, Nazifa, and Mohamed (2019) similarly finds that the integration of FM in AE-design phases provides designers with first-hand knowledge that has positive impacts and helps lead to reduced operations and maintenance costs. Mohammed and Hassanain (2010) find that a failure to integrate FM in design is sure to result in a property's loss of value through increased cost and time for renovation, retrofitting, and refurbishment. Erdener (2003) finds that when FM is integrated into the design process, building operations are more successful, and user satisfaction increases. Meng (2013) finds an increasing recognition of the importance of involving FM in early design and finds that FM involvement in design benefits FMs and benefits other key stakeholders such as clients, designers, and end-users. When FM specialists are not involved in the design, Meng adds that critical problems may occur, such as lack of operability, maintainability, and serviceability. Meng reaffirms the value of FM-design integration by stating, "The effect of early FM involvement can be seen in the avoidance of design defects" (2013, p. 506).

Table 1.4: Summary of benefits of FM-design engagement

Summary Benefits of FM-Design Engagement – Select Authors	
1.	Better selection of equipment and materials (Jawdeh et al., 2010)
2.	Equipment easier to access (Jawdeh et al., 2010; Liu, Lavy, & R.A. Issa, 2014)
3.	Facility better suited to meet business needs (Isa, Kamaruzzaman, Mohamed, & Berawi, 2017; Jaunzens et al., 2001)
4.	Facility easier to commission (Jaunzens et al., 2001; Jawdeh et al., 2010)
5.	Facility more attractive to clients, improved user satisfaction (Jaunzens et al., 2001) (Erdener, 2003)
6.	Facility more cost-effective to operate (Islam et al., 2019; Jaunzens et al., 2001; Meier & Russell, 2000; Tucker & Masuri, 2016; Weeks & Leite, 2021)
7.	Improved operational efficiencies, easier to operate the facility (Arditi & Nawakorawit, 1999; Bröchner, 1996; Fatayer et al., 2019; Isa et al., 2017; Jaunzens et al., 2001; Meier & Russell, 2000; Meng, 2013)
8.	Improved space management, facility better able to respond to user and occupant needs (Isa et al., 2017; Jaunzens et al., 2001)
9.	Increased property value (Boge et al., 2018; Mohammed & Hassanain, 2010)
10.	Reduced cost and time for renovations, retrofitting, and refurbishment (Mohammed & Hassanain, 2010)
11.	Reduced design defects and errors, improved design processes (Edum-Fotwe, Egbu, & Gibb, 2003; Erdener, 2003; Fatayer et al., 2019; Meng, 2013)
12.	Reduced maintenance problems and easier to maintain (Arditi & Nawakorawit, 1999; Bröchner, 1996; Fatayer et al., 2019; Isa et al., 2017; Jaunzens et al., 2001; Meier & Russell, 2000; Meng, 2013; Weeks & Leite, 2021; Zhu, Shan, & Hwang, 2018)
13.	Reduced waste (Erdener, 2003)

1.2.6 Observed Problem

Despite the potential benefit from an increased involvement of FM in AE-design, multiple researchers find the sharing of knowledge between design and FM teams is limited (Anh Thi Lê & Brønn, 2007; Bröchner, 1996; Jaunzens et al., 2001; Jensen, 2009, 2012; Kalantari et al., 2017a; Kalantari et al., 2017; Mohammed & Hassanain, 2010; Rasmussen et al., 2019). Furthermore, even experienced facility owners and operators with internal facility management divisions have been shown to struggle to utilise the knowledge they possess in the building projects (Jensen, Rasmussen, & Chatzilazarou, 2019; Rasmussen & Balslev, 2014; Rasmussen & Jensen, 2018; Weeks & Leite, 2021).

To address the limited connection between AE-design and FM, prior research finds a need to establish systems of communication between FM and design that facilitate the sharing of knowledge and expertise from operation to design (Emmitt, 2007; Fatayer, 2012; Göçer, Hua, & Göçer, 2015; Jensen, 2012; Kalantari et al., 2017a; Kalantari et al., 2017; Meng, 2013).

The potential for sharing FM knowledge with AE-design is also supported by research suggesting design teams will become more multidisciplinary as advanced construction and information modelling systems become widely adopted (Meng, 2013). In addition, Anh Thi Lê and Brønn (2007), Bröchner (1996), Emmitt (2007), Fatayer et al. (2019), Jensen et al. (2019), (Liu & Issa, 2016), and Weeks and Leite (2021) suggest improvements in information technology will support FM-design knowledge sharing; however, they find there are persistent gaps in tools and methods necessary to effectively share knowledge between FM and design teams. Erdener (2003, p. 8) finds that a similar gap in communication between the parties involved in the designing, building, and operation of facilities leads to a disconnect between "client and user expectations and the degree to which facilities satisfy those requirements." This prior research suggests opportunities to develop solutions that improve information and knowledge sharing across a project's design, construction, and operational lifespan.

1.3 Research Aim and Objectives

Having identified the observed problems which led to this research, this study defines the following research aim and objectives.

1.3.1 Research Aim

This research aims to develop solutions that facilitate information and knowledge sharing between FM/O and AE-design teams.

1.3.2 Research Objectives

The following objectives support the research aim:

1. Identify barriers to sharing facility management and operations information and knowledge with AE-design teams.
2. To identify what information is available from facility management and operations to support AE-design decision-making process.
3. To identify how facility management and operations information and knowledge can be shared with AE-design teams.
4. To develop and validate a conceptual framework that supports AE-design decisions by facilitating information and knowledge sharing between facility management and operations and AE-design teams.

1.4 Outline Research Methodology

A research methodology helps us describe and understand the different ways in which knowledge is created. It asks the question, "how should we study the world?" (Patton, 2009). Therefore, selecting an appropriate research methodology is inherently dependant on the proposed research aim or question. However, before identifying an appropriate research strategy, it is necessary to define the research's ontological, epistemological, and axiological assumptions.

Ontological Assumption:

Reality exists and can be studied and understood. In the context of this research, design exists as a phenomenon that can be studied.

Epistemological Assumption:

There are different types of knowledge, ranging from textual and visual data to numerical data, from facts to opinions, from narratives to stories. Knowledge can be gained through the act of making and that iterative circumscription can reveal meaning. In the context of this thesis, design is an intentional activity engaged in by designers. A legitimate knowledge of design can be gained from active involvement in the design process.

Axiological Assumption:

Improving the design process and related built environment is a worthwhile endeavour. Designers and facility managers have meaningful contributions to make in the design process and investigating their opinions is warranted. The opinions of designers and facility managers have value in a study of design-related matters.

Research Strategy – Design Science:

Because the stated research aim is to develop solutions that facilitate information sharing between FM/O and AE-design teams, a prescriptive rather than descriptive research method is required. This research uses a design science research (DSR) strategy due to its ability to guide research focused on proposing solutions to existing problems through the generation and creation of artefacts. According to Dresch, Lacerda, and Antunes (2015), DSR is an appropriate choice for research that seeks to produce systems that do not exist, modify existing situations to achieve better results, or find solutions to identified problems (see also Aken, 2004; Johannesson & Perjons, 2014).

A DSR strategy allows the research to focus on developing an artefact that fulfils the research aim. According to Kehily and Underwood (2015), traditional academic research describes phenomena within existing realities, rather than prescribing solutions that change reality, while design science facilitates the proposal and evaluation of new ways of working (that is to say, new realities).

The DSR strategy used for this study relied on a mixture of qualitative and quantitative techniques: including a systematic literature review, interviews, and an online questionnaire. Additional details about the research methodology and DSR strategy used in this thesis are presented in Chapters 3 and 4.

1.5 Research Scope and Limitations

This research discusses built environment industries in the UK and US. However, as the study takes place in the US, and the research participants and respondents are mainly from the US, the research's scope is limited to US AE and FM/O industries with a focus on the midwestern region of the US. In addition to this geographic limit to its scope, the thesis includes other limitations that narrow its focus.

The focus of this thesis is the provision of knowledge *from* FM *t*o AE-design. The research's aim limits its scope to the development of solutions that support design decisions through the sharing or transfer of knowledge, information, data, and feedback between FM/O and AE-design. To this end, the research focuses on conceptual rather than detailed solutions by developing conceptual aspects of the studied domain and an associated framework, rather than creating fully functioning artefacts.

Participants in the research study either worked in an AE-design-related capacity or within organisations that employ facility managers. Both AE and FM/O respondents worked in a range of industry sectors. While this range of experience contributes to the generalisability of the research's findings, the findings may not apply to all building and facility types.

In fulfilling the study's aim, the research focused on one area of knowledge sharing within AECO standard processes, between FM/O and AE-design to support design decision-making processes. Alternatively, it could have looked at knowledge sharing across the whole design, construction, and operations process. However, it is impossible to explore all these areas within one doctoral thesis because of limitations in time and resources. Therefore, due to the nature of the problems examined, the benefits reviewed in this chapter, and the background of the research candidate, the research focused on the connection of FM knowledge to AE-design processes. This focus limits its scope to one aspect of the AECO project life cycle.

In addition, the DSR strategy further narrows the research scope as it leads to the development of an artefact that seeks to address the identified research aim. However, focusing on developing an artefact or artefacts does not preclude alternative methods for addressing the research aim.

The length of time associated with AECO life cycles represents another limitation to the research. Proposals for supporting the provision of knowledge from FM into AE-design were not tested on ongoing design and construction projects to evaluate their effectiveness. To thoroughly test the identified solutions to the research aim would require a longitudinal study to validate the research findings over a built project's full life cycle and across multiple projects, which is beyond the scope of a single thesis. These limitations may in part be overcome in future research by:

1. Using a longitudinal study to validate the research findings over a built project's complete life cycle and across multiple projects;
2. Undertaking similar research with different research methodologies (such as case study or action research); and
3. Expanding the respondent pool to a larger geographic area.

1.6 Contributions to Knowledge

This research contributes to the literature and practice through the articulation of a DSR artefact (presented as a framework) that supports information sharing between FM/O and AE-design teams. Where previous researchers emphasised the benefits of, and barriers to, increased AE-FM information sharing, this study went further in its goal of developing solutions that facilitate information sharing between FM/O and AE-design teams. These solutions create project value by facilitating FM/O – AE information sharing to support design decision-making processes by providing structured, accurate, relevant, and timely information at the appropriate stages of the design process. Improving access to FM knowledge that supports design decision-making processes is expected to strengthen AE-design decisions, which in turn is expected to improve the overall quality of the built environment. In addition, data collected through the research process – semi-structured interviews, online questionnaire, and validation interviews – add to the understanding of barriers to, and opportunities for increasing FM input during AE-design.

1.7 Thesis Structure

This thesis is divided into the following chapters plus appendices:

1.0 Introduction: Provides an introduction and outline of the thesis structure. Summarises research background, motivation, research aim, objectives, methodology, scope, limitations, and knowledge contribution.

2.0 Literature Review: Reviews the literature used to establish the theoretical foundation for fulfilling the research aim**.**

3.0 Research Methodology: Describes the research methodology in detail.

4.0 Research Design: Describes the research design for semi-structured interviews, online questionnaire, and semi-structured validation interviews.

5.0 Interview Data Review and Analysis: Analyses data and discusses findings associated with semi-structured interviews.

6.0 Questionnaire Data Review and Analysis: Analyses data and discusses findings associated with an online questionnaire.

7.0 Conceptual Framework: Describes a framework for supporting knowledge sharing between FM/O and AE.

8.0 Framework Validation and Research Discussion: Reviews the development and refinement of the framework and discusses its validation**.**

9.0 Conclusion: Summarises key findings and contributions to knowledge. Discusses project limitations and makes suggestions for future action.

1.8 Chapter Summary

This chapter introduces the context and motivation behind this thesis. A summary of relevant literature is provided as a basis for the establishment of the associated aim and objectives. An outline of the research methodology is presented, and in conclusion, the structure for the thesis is presented.

2. LITERATURE REVIEW

2.1 Chapter Introduction

Chapter 1 introduced the structure of the thesis. This introduction provided an overview of the literature used to identify the observed issues that led to the research study and to establish the research aim and objectives. Chapter two expands the literature review from Chapter 1 to further frame the research aim and objectives and support their fulfilment.

According to Creswell and Creswell (2018, p. 26), a literature review "provides a framework for establishing the importance of a study as well as a benchmark for comparing results with other findings." Literature reviews relate a piece of research to larger ongoing dialogues in the literature and may fill in gaps or extend prior studies.

Cooper (2015, p. 5) categorises four literature review types, each based on different goals, and adds that literature reviews can have more than one goal.

1. To integrate or compare and contrast what others have done and said,
2. To criticise previous scholarly works,
3. To build bridges between related topic areas, and/or
4. To identify the central issues in a field.

Petticrew and Roberts (2006, as cited in Cooper, 2015) add an additional type of literature review and an associated goal. They identify what they call a *rapid review* or *scoping review*. They suggest this type of literature review can be used to help researchers refine their research aim or to gauge the feasibility of conducting a full review.

Working within these literature review classifications, Creswell and Creswell (2018) state that literature reviews for most student dissertations or theses seek to integrate the literature, to organise it into a series of related topics, and to summarise the central issues related to a topic. However, they suggest literature reviews in qualitative, quantitative, and mixed methods research may each be structured differently.

In qualitative studies, the literature review may be included in the introduction to provide a backdrop for the issue(s) being studied; it may be placed in a separate section near the beginning of a study; or it may be placed in a final section used to compare the results of a study with other works (Creswell & Creswell, 2018).

In contrast, Creswell and Creswell (2018) suggest that a literature review for quantitative research typically includes a significant literature review at the beginning of a study to guide the research question or hypothesis. It introduces a theory or problem and suggests why it is important to examine. The literature review is then revisited at the end of a study to compare the results and the existing literature. Creswell describes this model of literature review as a deductive framework for establishing a research question or hypothesis.

In mixed methods research, Creswell and Creswell (2018) suggest varying approaches to the literature review may be used depending on the type of research strategy being used at a given point in the study. For example, in a sequential approach, literature may be presented in each phase of the research according to the research strategy in use at that time. In this manner, the literature review may be found throughout a study instead of singularly at the beginning or end.

This thesis used an approach to its literature review based on the mixed method literature review approach described by Creswell and Creswell (2018). At various points throughout the thesis, different literature reviews were utilised depending on the phase of the study or type of research being performed. In Chapter 1, a *scoping review* was used to identify the central issues in the field of study and to define the research aim and objectives. In the beginning of Chapter 2, a systematic review was undertaken to identify what others have done and said about the research aim and to support the fulfilment of the research objectives. Finally, a broader review was used to build bridges between related topic areas. This more general review of relevant theory served as the basis for subsequent parts of the research and was carried out over the project's duration. In keeping with the suggestion by Creswell and Creswell (2018) that mixed methods literature review may be found throughout a study as opposed to singularly at the beginning or end, this broader review can be found throughout the thesis.

2.2 Scope and Method of Literature Review

The literature review undertaken for this research was based on two primary methods, a *backward* and *forward* approach (or *snowballing*) and a systematic review using Boolean Operator search terms within databases of peer reviewed articles.

2.2.1 Scoping Literature Review Method

In the first phase of the literature review, a scoping review was utilised to establish the research aim and objectives. This search for relevant literature began with a snowball or backward and forward approach to the literature review (Watson & Webster, 2020; Webster & Watson, 2002; Wohlin, 2014). In this approach, key articles known to the researcher were used as a starting point. The citations in these papers were then followed both forwards and backwards to identify additional literature sources for consideration.

- **Backward:** citations in key articles were reviewed to identify additional articles for consideration.
- **Forward:** using Scopus by Elsevier, the Salford Library search database, and Google Scholar, articles published after the original articles, but that cited the original key sources were identified for consideration.

Both the original set of key papers and new papers identified through the initial forward and backward approach were then reviewed for keywords. These keywords were used to search for additional articles using Scopus, Proquest, the University of Salford Library search database, the Ferris State University Library search database, and Google Scholar. New sources found in these keyword searches were then included in new forward and backward searches, such that there was a continuous back and forth between backward and forward and keyword searches until no new relevant items were found.

In this initial literature review, peer reviewed journal articles were prioritised. Books were generally omitted because related research is often published in articles alongside books. However, books were included when they were repeatedly referenced in the selected journal articles. Similarly, conference papers and government or industry documents were omitted unless they were regularly cited by selected peer-reviewed articles or if they provided unique and specific information not available in other sources.

This initial scoping literature review was used to establish the research aim and objectives and provided the basis for the subsequent systematic literature review.

2.2.2 Systematic Literature Review Method

The initial scoping literature review findings were used as a basis for a systematic literature review primarily aimed at addressing research objective one and three. Similarly, new sources found through the systematic literature review were used to reinforce the findings from the scoping review discussed above.

In the systematic literature review, Boolean Operators were added to the search for relevant papers. These Boolean Operators were based on keywords identified in the initial scoping review. Using the Scopus multidisciplinary database provided by Elsevier, keyword searches were performed using the Boolean Operators listed in Table 2.1.

Table 2.1: Systematic literature review Boolean Operators

Boolean Operators – Search Terms			
knowledge ***and***	**transfer** ***and***	**“building operation*”** ***and***	**“building design”** ***and***
OR information	OR integration	OR “operation* and maintenance”	OR design*
OR data	OR provide	OR "facility* management"	OR architect*
OR experience	OR feedback	OR FM	OR engineer*
OR Learn*	OR shar*		

The Scopus search (Table 2.3) initially returned 2,770 results. This search was then filtered using the criteria identified in Table 2.2. This additional filtering reduced the number of articles to 418.

Table 2.2: Systematic literature review search filtering criteria

Scopus Search Filtering	
Filter Category	**Criteria**
Language	English
Sources	Peer reviewed articles
Date range	Articles published between 2000 – 2022
Subject area	Non-relevant research fields were omitted such as Medicine, Veterinary Sciences, Agriculture

Following the filtering of the Scopus search, the remaining 418 articles were reviewed by the researcher to determine their relevance. The title, keywords, and abstracts were reviewed, and non-relevant articles were excluded. After this additional review, 14 articles were identified as relevant to the intention of the literature review. These 14 articles were then expanded upon by conducting similar Boolean Operator searches and reviews in three other databases: Web of Science, ScienceDirect, and the American Society of Civil Engineers (ASCE)

Library. While Scopus represented the primary database, these other databases were added to reduce the possibility of missing pertinent or important articles for inclusion in the literature review. Based on this additional review, three articles were added based on the Web of Science search, no new articles were added based on the ScienceDirect search, and four articles were added based on the ASCE Library search. Additionally, the forward and backward approach discussed previously was used to search for additional articles, resulting in 38 total sources for further analysis. (Table 2.4).

Table 2.3: Scopus search code

```
(TITLE-ABS-KEY(knowledge)
OR TITLE-ABS-KEY(information)
OR TITLE-ABS-KEY(data)
OR TITLE-ABS-KEY(experience)
OR TITLE-ABS-KEY(learn*)
AND TITLE-ABS-KEY(transfer)
OR TITLE-ABS-KEY(integration)
OR TITLE-ABS-KEY(provide)
OR TITLE-ABS-KEY(feedback)
OR TITLE-ABS-KEY(shar*)
AND TITLE-ABS-KEY("building operation*")
OR TITLE-ABS-KEY("operation* and maintenance")
OR TITLE-ABS-KEY("facilit* management")
OR TITLE-ABS-KEY(FM)
AND TITLE-ABS-KEY("building design")
OR TITLE-ABS-KEY(design*)
OR TITLE-ABS-KEY(architect*)
OR TITLE-ABS-KEY(engineer*)
)
AND PUBYEAR > 2000
AND PUBYEAR < 2022
AND (
LIMIT-TO ( SRCTYPE,"j" )
)
AND (
LIMIT-TO ( DOCTYPE,"ar" )
)
AND (
EXCLUDE ( SUBJAREA,"ENVI" )
OR EXCLUDE ( SUBJAREA,"ECON" )
OR EXCLUDE ( SUBJAREA,"ENER" )
OR EXCLUDE ( SUBJAREA,"MEDI" )
OR EXCLUDE ( SUBJAREA,"NURS" )
OR EXCLUDE ( SUBJAREA,"EART" )
OR EXCLUDE ( SUBJAREA,"AGRI" )
OR EXCLUDE ( SUBJAREA,"BIOC" )
OR EXCLUDE ( SUBJAREA,"CENG" )
OR EXCLUDE ( SUBJAREA,"MATH" )
OR EXCLUDE ( SUBJAREA,"CHEM" )
OR EXCLUDE ( SUBJAREA,"HEAL" )
OR EXCLUDE ( SUBJAREA,"IMMU" )
OR EXCLUDE ( SUBJAREA,"NEUR" )
OR EXCLUDE ( SUBJAREA,"COMP" )
OR EXCLUDE ( SUBJAREA,"PHYS" )
OR EXCLUDE ( SUBJAREA,"MATE" )
OR EXCLUDE ( SUBJAREA,"PSYC" )
OR EXCLUDE ( SUBJAREA,"DENT" )
OR EXCLUDE ( SUBJAREA,"PHAR" )
OR EXCLUDE ( SUBJAREA,"VETE" )
)
AND (
LIMIT-TO ( LANGUAGE,"English" ))
```

Table 2.4: Systemic literature review sources

Author(s)	Journal	Country/Region	Search
Alwan and Gledson (2015)	Built Environment Project and Asset Management	United Kingdom	Backward/Forward
Anh Thi Lê and Brønn (2007)	Engineering, Construction and Architectural Management	Norway	Backward/Forward
Arditi and Nawakorawit (1999)	Journal of Architectural Engineering	United States	Backward/Forward
Boge et al. (2018)	Facilities	Norway	Scopus – Key Word
Bröchner (1996)	Book	Not noted – Author from Sweden	Backward/Forward
Bröchner (2003)	Journal of Performance of Constructed Facilities	Not noted – Author from Sweden	Scopus – Key Word
Chandra and Loosemore (2011)	Construction Management and Economics	Australia	Backward/Forward
Edum-Fotwe et al. (2003)	Journal of Performance of Constructed Facilities	United Kingdom	ASCE – Key Word
Emmitt (2007)	Blackwell (Book)	United Kingdom	Backward/Forward
Erdener (2003)	Journal of Performance of Constructed Facilities	United States	Web of Science – Key Word
Ergen, Kula, Guven, and Artan (2021)	Journal of Computing in Civil Engineering	Turkey	ASCE – Key Word
Fatayer et al. (2019)	International Journal of Building Pathology and Adaptation	Saudi Arabia	Scopus – Key Word
Göçer et al. (2015)	Building and Environment	United States	Backward/Forward
Hassanain, Al-Hammad, and Fatayer (2014a)	Architectural Science Review	Saudi Arabia	Web of Science – Key Word
Hassanain, Al-Hammad, and Fatayer (2014b)	Architectural Science Review	Saudi Arabia	Web of Science – Key Word
Hassanain, Fatayer, and Al-Hammad (2015)	Journal of Performance of Constructed Facilities	Saudi Arabia	Backward/Forward
Hassanain, Fatayer, and Al-Hammad (2016)	Journal of Performance of Constructed Facilities	Saudi Arabia	Backward/Forward
Hen, Sarpin, Omar, Wee, and Chen (2021)	Research in Management of Technology and Business	Malaysia	Scopus – Key Word
Jaunzens et al. (2001)	Industry report	United Kingdom	Backward/Forward
Jensen (2009)	Architectural Engineering and Design Management	Denmark	Scopus – Key Word
Jensen (2012)	Architectural Engineering and Design Management	Denmark	Scopus – Key Word
Jensen et al. (2019)	Journal of Facilities Management	Denmark	Scopus – Key Word
Kalantari et al. (2017a)	Architectural Engineering and Design Management	United Kingdom, United States, Middle East	Backward/Forward
Kalantari et al. (2017)	Facilities	United Kingdom, United States, Middle East	Backward/Forward
Liu and Issa (2016)	Journal of Performance of Constructed Facilities	United States	Scopus – Key Word
Loosemore and Chandra (2012)	Built Environment Project and Asset Management	Australia	Scopus – Key Word
Menezes, Cripps, Bouchlaghem, and Buswell (2012)	Applied Energy	United Kingdom	Backward/Forward
Meng (2013)	Journal of Performance of Constructed Facilities	United Kingdom	Backward/Forward
Mohammed and Hassanain (2010)	The Built & Human Environment Review	Saudi Arabia	Backward/Forward
Oti, Kurul, Cheung, and Tah (2016)	Automation in Construction	United Kingdom	Scopus – Key Word
Pärn, Edwards, and Sing (2017)	Automation in construction	General	ASCE – Key Word
Rasmussen (2020)	Facilities	Denmark	Scopus – Key Word
Rasmussen et al. (2019)	Facilities	Denmark	Scopus – Key Word
Støre-Valen (2021)	Facilities	Norway	Scopus – Key Word
Weeks and Leite (2021)	Journal of Performance of Constructed Facilities	United States	Scopus – Key Word
Wong, Kumaraswamy, Mahesh, and Ling (2014)	Journal of Facilities Management	Hong Kong, United Kingdom, Singapore, Sri Lanka	Backward/Forward
Y. Wang, Wang, Wang, Yung, and Jun (2013)	Advances in Civil Engineering	China	Backward/Forward
Zhu et al. (2018)	Journal of Performance of Constructed Facilities	Singapore	ASCE – Key Word

2.2.3 Systematic Literature Review Limitations

The systematic literature Boolean Operator search found a limited number of articles relevant to the research study. Based on the experience of performing the literature search and associated study, the author suggests this is because the terminology used to discuss the involvement of FM in AE-design processes is broader and more varied than initially anticipated. Because of this, the systematic search was supplemented and expanded upon using forward and backward searches.

The Boolean Operator search and keyword searches often returned articles related to the transfer of information from AE to FM, which was the opposite direction of information flow sought. In their research, Rasmussen, Jensen, and Gregg (2017) found similar results, which they suggest indicates information sharing from AE to FM is more researched than the inverse – FM to AE.

An additional limitation of the systematic search was its primary focus on peer reviewed journal articles and exclusion of Grey Literature, such as governmental or industry sources. According to Dresch et al. (2015), traditional empirical sources used in systematic literature reviews, such as academic databases and peer reviewed journals, are often insufficient in a DSR strategy. The authors add that within a DSR strategy (as adopted for this study - see Chapter 1.4 and Chapter 3), the use of Grey Literature, and expert consultation, is appropriate and recommended. To overcome this limitation, Grey Literature was considered in backward and forward and keyword searches when the material was repeatedly cited in other, peer-reviewed articles.

2.2.4 Ongoing Literature Review

The third phase of the literature review included a broad review of relevant theory related to research objectives two through four and other aspects of the study. This phase of the literature review was used to make connections between related topic areas and to support subsequent parts of the research. This phase of the literature review was carried out across the duration of the research project and was primarily based on keyword, and backward and forward searches (Watson & Webster, 2020; Webster & Watson, 2002; Wohlin, 2014). In keeping with the suggestion by Creswell and Creswell (2018) that mixed methods literature review may be presented in each phase of the research in a manner consistent with the research strategy in use at that time, this third phase of the literature review is found throughout the whole of the study as opposed to singularly in Chapters 1 or 2.

2.3 Barriers to FM Involvement in AE-Design

As indicated in Chapter 1, prior research has documented the benefits of FM involvement in AE-design processes. This prior research is accepted as established research and was used to help identify a basis for this study. Within this prior research, Støre-Valen (2021) finds the benefits and importance of involving FM in AE building design phases have gradually been recognised as important by researchers. Støre-Valen further notes that it is not a question of if FM should be involved in the AE-design process, but rather *how* and *when*.

Despite the demonstrated benefits including FM in early design, researchers have persistently found barriers limiting such involvement (Jensen et al., 2019). Speaking of early Swedish efforts to increase FM involvement in early design, Bröchner (1996) concluded the necessary incentives to support such knowledge transfer was lacking and that the integrated development of design and facility services was a distant reality.

Jaunzens et al. (2001) similarly found multiple barriers limiting FM involvement in AE-design processes resulting from the fact that facility managers are often ignored during a project's design phase because they are seen as lacking the necessary competencies and prestige to be accepted as equal partners during the design process. Jaunzens et al. categorised these barriers as stemming from:

1. a lack of mechanisms for transfer of FM knowledge,
2. the perception of facility managers within their organisation,
3. the perception of the facility managers within the design team, and
4. the facility manager's self-perception.

The work of Jaunzens et al. (2001) represents Grey Literature as it was a report commissioned and published by a facility management professional organisation – the British Institute of Facilities Management (BIFM). The report's findings came from a series of workshops held with BIFM members. Its conclusions, therefore, have a potential bias towards the importance and potential value of including FM in the AE-design process. However, it has been included in this thesis, and as a literature review source, due to its repeated citations in other peer-reviewed articles used in this thesis. Additionally, while the report was limited in its scope, its publication coincided with the start of a period that has seen an increase in interest and research on the subject (Jensen, 2009; Støre-Valen, 2021). Other researchers have expanded on Jaunzens et al.'s work, and it is therefore seen by the author as a starting point for a review of peer-reviewed literature on the topic.

Investigating the barriers and benefits of FM-design integration, Bröchner (2003) finds that to understand the limited role FM typically has in building design, it is necessary first to consider two fundamental aspects of AE-design. Bröchner suggests building design serves two primary functions – protective functions and supportive functions. Where protective functions serve to protect users from accidents and disasters, such as fires or earthquakes, and supportive functions enable a building to fulfil its intended purpose, such as providing for office, education, or hospitality functions. Bröchner's work suggests this dual nature of design creates a tension that serves to limit the potential for FM involvement with design. This is due, in part, because the professional nature of FM (Chapter 1, Section 1.2.1) can lead facility managers to view buildings from a supportive perspective. However, according to Bröchner, because much of the AE-design process is focused on protecting users from extraordinary accidents (such as structural failure or fires), versus the supportive perspective, the experience of FM is undervalued and their potential for assuming a broader role in design is diminished.

The lack of a defined role for FM in design is reflected in the findings of Mohammed and Hassanain (2010, p. 84) who note that as a part of traditional facility design processes, "the absence of the specific role attached to the facility manager in the integrated design team has contributed to the low participation of these professionals in the design stage." They further find that the lack of a role for facility managers as part of the design process is a significant barrier to FM involvement in design. This view is reiterated by Boge et al. (2018) who find, based on an online survey of 837 respondents from Norway's architecture, engineering, and real estate management industry, that the failure to include FMs on the agenda of early planning meetings limits FM involvement in AE-design phases.

The work of Meng (2013) identifies additional barriers to FM-design integration, which he categorises in terms of their sources: barriers from client organisations, barriers from design organisations, and barriers from FM organisations. Meng identifies these barriers as being grounded in cost, a lack of industry emphasis on whole life costing, and a lack of awareness from clients and design teams regarding the extent of FM roles and knowledge (see Figure 2.1, in Section 2.4). Meng further identifies the temporal separation of FM from design in the AECO lifecycle as an additional barrier to FM involvement due to the fundamental characteristic of the design and construction process. Since AE-design is primarily involved at the beginning of a facility's lifecycle, and FM is involved at the end, the two disciplines are temporarily separated and less likely to interact.

Wong et al. (2014) add to Meng's temporal barrier with findings from their research that asset managers and building design project managers work independently and with limited interactions. They also find that project stakeholders have competing priorities and that knowledge sharing from FM/O with other stakeholders is not always a priority.

Alwan and Gledson (2015) similarly reflect the findings of Meng (2013) and Wong et al. (2014). Based on a research project which included unstructured interviews with 20 AE and FM industry practitioners in the UK, they found that FM participation in the AE-design process is limited due to the traditions of the building design and construction process and the way projects are delivered, which limits the participation of FM in design decisions. They further find that FM concerns are not integrated into AE-design unless required by the client.

Additional barriers are noted by Liu and Issa (2016). Who, in a survey of AE and FM professionals in the United States, find a knowledge and technology gap between AE-design and FM professionals that limit FM integration in the AE-design process. The authors also find that participants in early design phases do not understand or have adequate knowledge about FM needs and requirements and are thus less able to incorporate them into the design process.

Kalantari et al. (2017, p. 559) examine obstacles that limit collaboration between FM and design and find that while there is increasing recognition of the value of collaboration between FM and design, barriers persist. They add that research on the topic "has seldom led to specific organisational recommendations and does little to address the difficulties related to communication between FMs and designers." Kalantari et al. further find both facility managers and designers identify a lack of shared terminology, a lack of knowledge management tools, a lack of institutional incentives, limited design budgets, and a general lack of awareness of what FM does limit the integration of FM perspectives into the design process (see also Kalantari et al., 2017a).

The difficulties in communicating between FM and AE designers as noted by Kalantari et al. (2017) is reflected in the work of others as well. Exploring the role of communication in integrating FM and design, Erdener (2003) found that low levels of communication among all the parties involved in the design process acts as a persistent barrier to FM-design integration. Fatayer et al. (2019) similarly find communication barriers to FM involvement with AE-design teams. In studying FM involvement in design development and review stages, within 10 universities in Saudi Arabia, Fatayer et al. (2019) find a lack of methods for facility managers to communicate directly with AE-design teams act as a barrier for integrating FM knowledge in AE-design processes. They further find that FMs' unfamiliarity with the design process limits their ability to contribute to design.

Jensen et al. (2019) use a case study to examine knowledge transfer from FM to project managers at the Technical University of Denmark. Collecting data through interviews with project managers and maintenance staff, they find that the lack of human resources and available time acts as a significant barrier limiting the inclusion of OM feedback to project managers. The review of project drawings and documents is time-consuming and resource-intensive, and OM leaders cannot devote the time necessary to provide a proper assessment of design documents and give feedback. The authors further find that a general lack of collaboration and universal objectives within the case study organisation further limited knowledge transfer.

Rasmussen (2020) concludes that a lack of operational consideration exists in design phases because operations is not a matter of concern for building design project managers. In addition, citing Hansen (2010, as cited in Rasmussen, 2020), Rasmussen suggests that AE designers suffer from information overload and make design decisions based on their individual areas of concern, regardless of the impact on FM/O. Rasmussen further finds that

AE designers are limited by their bounded rationality, which limits their ability to consider all interests and knowledge in design decision-making. This view is reflected in the work of other researchers such as Arditi and Nawakorawit (1999), who similarly find that design teams and project clients balance many interests in a project besides FM/O considerations.

In a review of the literature, Weeks and Leite (2021) find that operations and maintenance related information does not reach AE designers for various reasons. These reasons include designers not asking for the information, a lack of available maintenance data, a lack of technology to enable the sharing of information, and a general lack of consideration of operations and maintenance during design. The work of Weeks and Leite (2021) suggests a lack of feedback loops prevents FM knowledge and information from reaching AE-design teams. This view is similarly found by Oti et al. (2016) who similarly suggest that the lack of established feedback loops from building operations phases to design limits the integration of FM information into AE-design processes.

Expanding on the lack of a feedback loop to share FM knowledge and information with AE-design, Oti, Tah, and Abanda (2018) note that common approaches to learning from past projects is typically done without a formal framework for knowledge capture and reuse. They further find that information and knowledge from existing projects is stored in methods that are not easily shareable, such as text-based notes, emails, or phone calls; a finding also noted by Ergen et al. (2021). Since this information is not recorded or stored in a structured way, it cannot be shared with decision makers at relevant project stages. This creates a barrier that prevents an adequate feedback loop from forming that allows FM knowledge and information from being shared with AE-design teams. Pärn et al. (2017) similarly find a lack of data interoperability limits knowledge sharing and feedback loops between FM and AE. They find that the interoperability of data leads to unawareness of what data is available or useable, which leads to a “lack of alignment in supply and demand for FM data” (pg. 52).

In conclusion, Anh Thi Lê and Brønn (2007) find that a loss of institutional knowledge and poor knowledge management contribute to barriers limiting the integration of FM knowledge and experiences into AE-design phases. They also identify two general approaches to organisational knowledge management that can be used to describe barriers to FM knowledge integration in AE-design; codification factors that are *technology-focused* and *personalisation* factors that are expert or person-focused. These personalisation factors may also be thought of as social factors. Where codification strategies rely on employing technologies such as database systems to act as repositories of organisational knowledge or as means of communication, *personalisation* strategies rely on interpersonal contacts. Jensen (2009) similarly finds both barriers to, and solutions for, knowledge transfer from FM to AE-design are influenced by technical and social factors. When referring to proposed solutions to overcome these barriers, Rasmussen et al. (2017) similarly describes them as technical-idealistic, socio-idealistic, or a hybrid of both.

2.3.1 Summary of Barriers to FM Involvement in AE-Design

In summarising the barriers to FM integration reviewed in this section, the researcher suggests these barriers can be categorised as being grounded in *technical* issues, *social* factors, or a *hybrid* of both (Anh Thi Lê & Brønn, 2007; Jensen, Damgaard, & Kristiansen, 2009; Rasmussen et al., 2017). In Table 2.5 below, each identified barrier is classified by the researcher as technical, social, or hybrid. The rationale for the classification of each barrier is also provided in the table.

Additionally, in further analysis of the identified barriers to FM involvement with design, the barriers may also be classified by the nature of the barrier. In this manner, the researcher proposes these barriers may be classified as resulting from a lack of resources, knowledge gaps, the nature of the design process, and a lack of priority or incentives. This classification is also indicated in Table 2.5 and additionally in Table 2.6 below.

Table 2.5: Summary of barriers to FM involvement in AE-design

Summary of Barriers to FM Involvement in AE-Design – Select Authors

Factor	Type	Barriers	Barrier Classification Rationale	Referencing Authors
Hybrid	Lack of resources	Lack of knowledge management and ability to share information.	Authors referred to both a lack of technical resources that facilitate knowledge management as well as a lack of organisational policies and procedures that promote knowledge management. Knowledge management is further limited by a lack of resources.	(Anh Thi Lê & Brønn, 2007; Ergen et al., 2021; Kalantari et al., 2017; Oti et al., 2016; Oti et al., 2018; Pärn et al., 2017)
Hybrid	Lack of resources	Limited resources for both AE designers and FMs	AE designers and FMs lack both technical resources as well as time and human resources to be able to facilitate knowledge sharing between disciplines.	(Jensen et al., 2019; Kalantari et al., 2017a; Kalantari et al., 2017; Rasmussen, 2020)
Hybrid	Lack of resources	Poor communication	Interpersonal communication is lacking as well as technical tools to facilitate meaningful communication.	(Erdener, 2003; Fatayer et al., 2019)
Hybrid	Knowledge gap	Technology knowledge gap between AE and FM practitioners	There is a knowledge gap of general knowledge, such as how each discipline operates, or how to meaningfully contribute to the design process on the part of FM, as well as technical skills and knowledge gaps. For example, the lack of BIM skills found among FMs.	(Fatayer et al., 2019; Kalantari et al., 2017a; Kalantari et al., 2017; Liu & Issa, 2016)
Hybrid	Nature of design process	Relationship of AE and FM within AECO lifecycles	The inherent nature of building lifecycles places design and operation at opposite ends of the spectrum. Furthermore, designers and FMs typically do not work in proximity. However, the temporal and technical separation of AE-design and FM in project lifecycles can be addressed through increased interpersonal contact and technical tools.	(Alwan & Gledson, 2015; Bröchner, 1996, 2003; Meng, 2013; Wong et al., 2014)
Social	Lack of priority / incentives	Competing priorities and lack of incentives	Designers have competing priorities within a project and a lack of additional incentive to add to their design processes by considering potential FM contributions.	(Arditi & Nawakorawit, 1999; Kalantari et al., 2017a; Kalantari et al., 2017; Meng, 2013; Rasmussen, 2020; Wong et al., 2014)
Social	Lack of priority / incentives	Failure to ask	Literature suggests AE designers often simply do not ask for information from FM/O.	(Alwan & Gledson, 2015; Weeks & Leite, 2021)
Social	Nature of design process	Lack of defined role for FM in design processes	The AE-design process traditionally does not include a defined role in the design process for FMs. Similarly, FMs are often not included in design review or planning meetings.	(Boge et al., 2018; Mohammed & Hassanain, 2010)
Social	Knowledge gap	Perception of FMs (Owners, AE designers, and FMs themselves)	Owners and AE-design teams often have the perception that FM has little to add to the design process. FMs often have a similar self-perception that they have little to add.	(Alwan & Gledson, 2015; Jaunzens et al., 2001; Kalantari et al., 2017a; Kalantari et al., 2017; Meng, 2013)
Social	Knowledge gap	Unawareness of each other's professional disciplines	Designers have limited awareness of the FM concerns and challenges, and vice versa.	(Fatayer et al., 2019; Kalantari et al., 2017a; Kalantari et al., 2017; Liu & Issa, 2016)
Technical	Lack of resources / nature of design process	Lack of shared terminology between FM and AE-design	AE and FM disciplines rely on different terminology and ontologies to describe and track their work which makes it difficult to share knowledge and data.	(Kalantari et al., 2017a; Kalantari et al., 2017)
Technical	Lack of resources	Lack of tools or mechanisms to facilitate integration	There is a lack of technical tools and similar resources to enable the sharing of FM knowledge, information, and documented lessons learned with AE designers. The lack of tools is a technical barrier.	(Fatayer et al., 2019; Jaunzens et al., 2001; Kalantari et al., 2017; Oti et al., 2016; Weeks & Leite, 2021)j

Barrier classification by author

Table 2.6: Consolidated barriers by type – FM-design integration

Consolidated Barriers – FM-Design Integration	
Identified Barrier Types	**Factor Category**
1. Lack of resources	Hybrid
a. Tools	Technical
b. Time	Hybrid
c. Human resources	Social
d. Lack of knowledge management or classification	Hybrid
e. Bounded rationality	Hybrid
2. Knowledge gap	Social
a. Technical knowledge and skills	Technical
b. Unawareness of each other's disciplines – lack of awareness	Social
3. Nature of design process	Hybrid
a. Competing priorities	Social
b. Temporal and spatial separation	Technical
c. Different terminology	Hybrid
4. Lack of priority or incentive	Social

By examining prior research related to the barriers that hinder FM involvement with AE-design, it is possible to understand the issue better and to be better able to develop solutions that overcome such barriers. This review of the literature finds a range of consistent social, technical, and hybrid barriers that limit FM knowledge sharing with AE-design. Many of which have been documented by multiple researchers over many years. This points to the persistent nature of these barriers and to the difficulties of overcoming them. In addition, many of these barriers have been documented in disparate studies that looked at specific building types or industries and in various countries. While many of the studies reviewed were limited in their individual scope, the broad arc of the literature reviewed, and the repeated findings suggest the generalisability of individual research study findings. It further suggests opportunities to investigate the potential for such barriers within the defined scope of this research.

2.4 Proposals to Support FM Involvement in AE-Design

Despite the difficulty in overcoming the barriers that limit the sharing of FM knowledge and information with AE-design, multiple researchers have suggested a range of proposals to overcome these barriers. A review of these proposals is discussed in the following section. The presentation of these proposals is organised by their *primary* social, technical, or hybrid categorisation as categorised by this author. (These proposals are also summarised below in Table 2.12). The categorisation of each proposal by the researcher is not intended to be definitive as some proposals may straddle different categories. Furthermore, different researchers may see fit to categorise proposals differently. Rather, the categorisation is intended to aid in the presentation, organisation, and general understanding of these findings from the literature review.

Social Proposals:

Jaunzens et al. (2001) report on applying FM expertise in building design proposed that methods for improving FM knowledge sharing with design should focus on FM professional development rather than within the design team. Jaunzens et al. made clear the potential value of insights of FM professionals to design teams available from the but found mechanisms for transfer of that knowledge were lacking. Their report proposed a development plan for facility managers, included an FM self-assessment tool, and made recommendations for how FMs can be more empowered. Regarding the question of when FM should be involved with design, Jaunzens et al. (2001) further propose that FM expertise should be considered across multiple design phases (Table 2.7). However, by focusing on FM professional development, the suggestions by Jaunzen et al. lack a clear path for FM to be included in AE-design. As noted above, multiple researchers found the lack of awareness of FM expertise on the part of the designers and owners, as well as lack of incentives to include FM in AE-design, act as significant barriers. Therefore, Jaunzen et al.'s focus on increasing FM professional development alone is seen as insufficient in overcoming these barriers.

In contrast to Jaunzen et al., Erdener (2003) focuses on integrated communication processes and proposes that the programming phase represents an opportunity to link FM and design. Erdener further suggests a modified framework for the design and construction management of a facility to replace the common framework of predesign, design, construction, and post-occupancy. However, Erdener does not provide a direct role for FM in this integrated approach to design. Erdener's approach is similarly seen as lacking due to its focus on programming and revisions to the common AECO project lifecycle. While facilitating increased FM involvement in the programming stage allows FM knowledge to be included in project planning, it does not guarantee their expertise is included in later project phases or that FMs' initial input is included in the final built project.

Table 2.7: Jaunzens et al. FM involvement in design phases

Ideal Involvement of Facility Managers across Phases (adapted from Jaunzens et al., 2001)		
Project Phases*	**Activities to be undertaken**	**Typical problems arising if this activity is not carried out**
Strategic Definition	• Contributing to pre-briefing discussions	• Specifying a new building where refurbishment of an existing building would be appropriate.
Preparation and Briefing	• Inputting to strategic requirements relating to operational issues. • Giving advice on the requirements set within the brief. • Ensuring that end user's needs are incorporated into the planning process.	• Inflexible building services that cannot cope with organisational churn. • Inappropriate standards for environmental policy. • Inadequate control provided at an individual level.
Concept Design and Spatial Coordination	• Ensuring that strategic FM requirements have been incorporated into the design. • Contributing to the assessment of design. • Checking that the cost plan considers operational costs where this is required.	• Inadequate plant room space leading to difficulties with services maintenance. • Eliminating design features or failing to install backup systems leading to loss of business function. • A building that is too costly to maintain within the available resources.
Technical Design	• Reviewing the design and ensuring that functionality has not been compromised. • Reviewing the design and ensuring that operating costs meet financial criteria. • Checking design limitations.	• Inadequate access to services plant • Equipment that is difficult or costly to replace. • Overly complex design resulting in underperformance.
Manufacturing and Construction	• Ensuring that the chosen project bids comply with key requirements.	• Introducing unsuitable alternative solutions.
	• Ensuring that the commissioning procedures are appropriate. • Witnessing that commissioning has been properly carried out.	• Under-performing services resulting in occupant discomfort. • Excessive energy costs.
Handover	• Ensuring that handover documentation is adequate and complete. • Ensuring that facilities staff and end users have been instructed in using facilities.	• Misunderstanding of building operation leading to energy wastage and occupant discomfort.
Use	• Ensuring that post-handover services are in place (e.g., post-handover commissioning). • Obtaining information on building performance; ensuring that feedback is given to the design team and appropriate follow-up action is taken.	
*Based on the RIBA Plan of Work project stages (Sinclair, 2020).		

Continuing with Erdener's focus on programming, Mohammed and Hassanain (2010) note that when FM is integrated into design, it is typically done at the programming stage of design. However, because the nature of the design process typically results in many changes between programming and final design, they propose that FM should be integrated as part of the design team from the beginning of design through final design stages. Like Jaunzens et al., Mohammed and Hassanain put the burden of integration on FMs but do so by suggesting a new definition for FM in a design context, giving FM a central role within an integrated design team. However, finding a gap in the literature related to the integration of FM throughout the full design process, Mohammed and Hassanain (2010, p. 85) further propose "there is a need for further studies on the extent of the detailed contributions of the facility manager to the individual members of the design team."

Mohammed and Hassanain (2010) seem to suggest that simply by providing a role for FM within an AE-design team, FM knowledge can be shared and integrated with AE designers. However, this fails to address a range of barriers identified in the previous section, such as lack of FM knowledge management, lack of methods for sharing information, temporal gaps between the work of FM and AE, or the lack of knowledge and information codification.

Anh Thi Lê and Brønn (2007) present a learning perspective that considers an integrated organisational-learning model. Anh Thi Lê and Brønn combine individual and organisational learning to bridge the gap between individual mental and shared mental models, which represent different understandings of how the world works. Anh Thi Lê and Brønn further identify seven learning breakdowns within built environment industries (Table 2.8). They then propose that improved feedback from operation and maintenance to AE-design can be realised through improved methods of organisational learning and organisational initiatives that close the experience transfer loop, but they do not propose specific mechanisms for how this might be achieved.

Anh Thi Lê and Brønn further describe two general approaches to industry knowledge management: a technology-focused, codification strategy, and an expert focused, personalisation strategy. In the codification strategy, information technology and databases are used as a repository of institutional knowledge and act as a means of communicating this knowledge. In the personalisation strategy, knowledge maintenance and transfer are dependent on interpersonal contacts.

Table 2.8: Learning breakdowns linked to the building industry

Incomplete Learning Cycles	Application to the Building Industry
Role constraint learning	Few demanding customers, many participants with varying roles from project to project and fierce price competition.
Audience learning	Project participant’s learning has no effect on organisational action, the organisation, or the building industry.
Superstitious learning	Characteristics of production by orders that go into a relatively complicated “assembly process.”
Learning under ambiguity	Not many participants have an ownership or financial interest in the whole production chain.
Situational learning	Ad hoc organisations result in individually based and not organisational based experience transfer.
Fragmented learning	Difficult to discern differences between the operational work task and the designer’s work tasks.
Opportunistic learning	Almost no systemised and continuous learning process from project to project due to knowledge transfer.
(adapted from Anh Thi Lê & Brønn, 2007, p. 157)	

Loosemore and Chandra (2012) also propose a social factor-based solution to FM integration in early design. Based on qualitative data from one hospital case study in Sydney Australia, they propose a new model for the development of project briefs that includes end users and facility managers in the briefing process. While the research was based on a single case study, they propose it has high levels of validity, but acknowledge more research is needed in other contexts to confirm its generalisability. However, like Erdener's proposed briefing proposal discussed above, their focus on briefing suggests the potential for FM involvement to be reduced in later design phases and does not ensure FM input lasts throughout the full project cycle.

To address the question of FM involvement across all phases of design, Edum-Fotwe et al. (2003) document a case study of a single hospital design project in the UK. Within this case study FM involvement with the design team was achieved by "conducting periodic, documented, well-organised constructability reviews" (pg. 48) across the pre-design and design phases. This allowed FMs to track the inclusion of their concerns across the project's full development. Furthermore, this allowed the designers to research and consider the FMs feedback between meetings, as well as to incorporate it, offer alternatives, or reject FM requests with justification. Doing so enabled FM requirements to be integrated into the design and constructability process and was noted as having a significant impact on improving the design and construction process.

Menezes et al. (2012) addresses the question of FM and design integration at the other end of a project's lifecycle using post-occupancy evaluations (POE), specifically in addressing building performance gaps related to energy use. They argue the gap between predicted and actual energy performance is best addressed through an extended use of POE. They suggest an extended use of POE can be used to better integrate necessary and missing feedback from post-occupancy back to design. The purpose of which is to align design predictions with reality, rather than attempting to adjust reality to align with design predictions. In contrast, Ergen et al. (2021) are sceptical of the potential of POEs on their own to share FM related knowledge with AE-design teams. Ergen et al. found in their research that FM teams viewed POEs as ineffective to identifying building problems as they do not provide feedback on a continual basis, thus questioning the ability of traditional POEs to provide meaningful feedback from FM to AE-design teams.

Based on a quantitative survey of FM contractors in Malaysia, Hen et al. (2021) propose a solution to FM integration in project design stages that relies on three primary approaches to FM design integration: 1) Facility managers should participate in the preparation of the design brief; 2) Facility managers should routinely review design submissions to confirm if FM requirements are incorporated into the design; and 3) Facility managers should review design submissions and various stages of the design project, such as concept design, schematic design, design development, and should participate in the selection of design alternatives.

Hybrid Proposals:

To overcome the limitations of traditional POEs, Ergen et al. (2021) proposes the development of an asset information model (AIM) based semantic data model to store and share occupant feedback with design decision makers. Göçer et al. (2015, p. 15) similarly suggest existing POE methods overlook the potential for POE to link feedback from the operation of newly constructed buildings to design and proposes a new vision for how POE can “close the building performance feedback loop to better inform building design.” They similarly propose an integrated BIM and GIS communication platform to improve POE methods and to increase quantitative data sharing. According to Göçer et al., such methods have the potential to bridge performance gaps by providing more realistic data inputs to design; however, it is not clear how such BIM enabled POEs can overcome the noted technical skills gap between AE and FM teams.

Based on interviews of over 30 experts in the UK, Meng (2013) addresses proposals for overcoming barriers to FM-design integration. His proposals include paying more attention to FM’s role across a facility’s lifecycle, placing more emphasis on whole life costing, improving FM educational standards, improving opportunities for occupant feedback, and improving communication between designers, clients, and FMs (Figure 2.1). Meng (2013, p. 506) also calls for additional research “to better understand the value of incorporating FM expertise into design.” Meng’s review and proposals are broad in their nature but fail to propose actionable proposals that can lead to increased FM involvement with AE-design teams.

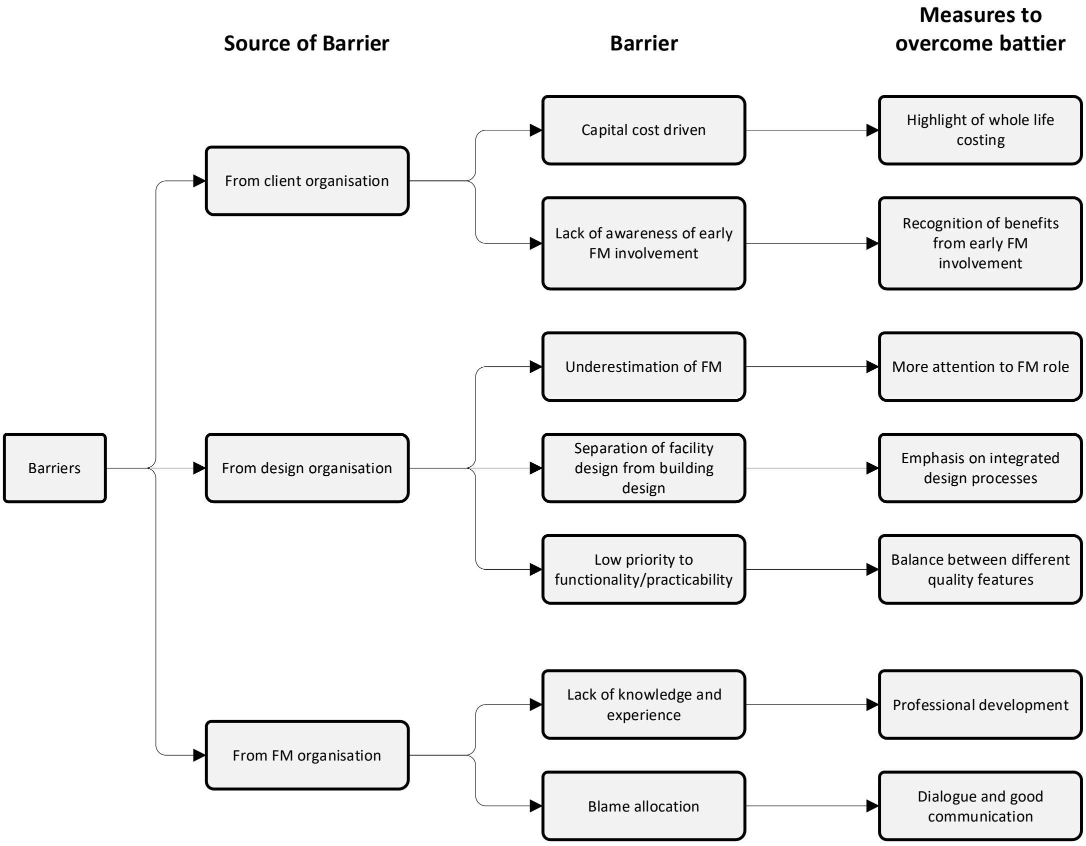


Figure 2.1: FM – AE-design integration barriers and associated strategies
(adapted from Meng, 2013)

Bröchner (2003) explores the relationship of FM and design from an economic efficiency viewpoint and finds it is the responsibility of a facility manager or building owner, as the source of customer requirements, to provide missing FM information to AE teams. Bröchner further suggests that FM integration with design can be supported by developing new IT tools that analyse best practices in FM but does not develop specific recommendations or tools to do so.

Meier and Russell (2000) propose a model for incorporating OM knowledge into the building design processes through a series of review meetings. Their model was developed based on a mixed method research project that included a questionnaire survey, 35 interviews with industry professionals, and six in-depth case studies in the United States. Based on this research they developed a model with a series of project milestones and project review meetings in which OM knowledge and feedback is provided to design teams and reviewed for its implementation from previous project phases. The model also proposed the development of a database of lessons learned for reuse on future projects.

Emmitt (2007) takes a learning perspective in addressing the question of how information from post-occupancy can be better integrated into the design of new buildings. In this context, Emmitt emphasises the role of FM and suggests that an increased focus on the value of commercial buildings has put an important emphasis on the links between facility managers and designers, noting that, “Increased interest in both building and service maintenance, coincident with the growth in the facilities management discipline, has brought a greater awareness of the value of accurate, accessible information” (Emmitt, 2007, p. 157). Emmitt further emphasises the potential for technology and computer software to aid in the quick retrieval of information from past projects.

Jensen (2012), a prolific writer on the topic of FM integration in design, suggests a range of hybrid solutions for improving knowledge sharing between FM and AE-design. He also suggests a key problem in the building industry is the limited degree of learning from the experiences of existing buildings in use and operation (see also, Jensen, 2009; Jensen et al., 2019). According to Jensen (2009, pp. 124-125), professional development of FM can act as “the missing link to bridge the gap between building operation and building design.” In his research, Jensen proposes key aspects of FM that should be considered across design stages:

1. transfer of experiences from existing buildings,
2. incorporation of considerations for operation and sustainability,
3. requirements for documentation about the new building,
4. considerations for user needs,
5. planning and organisation of the coming building operation, and
6. interior space and move planning.

Jensen (2009, p. 126) further specifies these tasks in relation to different design phases (Table 2.9). Of these tasks, in relation to facility design, he identifies the “incorporation of considerations for operation, sustainability and user needs” as most important. He elaborates that the incorporation of “user needs should include user involvement and follow-up on the building brief during design” (Jensen, 2002, as cited in Jensen, 2009). Furthermore, these tasks include a range of factors related to a building’s whole lifecycle, of which the most important are:

1. flexibility and adaptability in relation to changing needs over time;
2. logistics in relation to internal communication, transport and distribution;
3. ease of maintaining and cleaning the building and the surrounding areas;
4. possibilities to replace and reuse building parts;
5. safety and security of the building, persons, and assets;
6. energy and resource consumption (electricity, heating, cooling, water, et cetera);
7. environmental impact on the surroundings (pollution, noise, dirt);
8. indoor climate and working conditions; and
9. building management systems and installations.

Table 2.9: FM-specific tasks based on facility project phases

Building Project Phase	FM-Specific Tasks
Decision	• Incorporating real estate strategies • Information on space needs et cetera • Estimation of impacts on the cost of FM
Briefing	• Organisation of user involvement • Formulation of considerations for operation and sustainability • Overall requirements for documentation
Design	• **Incorporation of considerations for operation, sustainability, and user needs*** • Formulation of an operational concept • Formulation of requirements for building automation system
Construction	• Interior planning • Prepare commissioning • Contracting-out operational tasks
Facility Occupation	• Move • Handling former building(s) • Implementation of operational procedures
* Identified by Jensen as the most important FM task related to design (adapted from Jensen, 2009).	

According to Jensen et al. (2019), the transfer of knowledge between FM and design can be seen as a knowledge push from building operation to design, and as a knowledge pull from design (Table 2.10).

Table 2.10: Knowledge push and knowledge pull between FM and AE

Knowledge Push and Pull from OM to Project Management (PM)		
Mechanism	**Direction**	**Examples**
Push	OM → PM	Design standards (generic)
	PM → OM	Phase gate meetings: information about the project is given to OM
Pull	OM ← PM	Documents and drawings put in information and communication technology (ICT)-based tools
	PM ← OM	Phase gate meetings: feedback from OM
(adapted from Jensen et al., 2019)		

From a *knowledge push* viewpoint, better transfer of knowledge from FM to design is dependent on a better *codification* of knowledge from building operation, as well as improved competencies among facility managers. From a *knowledge pull* perspective, improved knowledge transfer between FM and design is dependent on better awareness among designers of the insights available within FM knowledge. It is also dependent on the amount of weight given to requirements to take building operations into account during design phases. According to Jensen, multiple strategies are therefore needed to improve the integration of FM into design, and he further identifies four transfer initiatives to facilitate knowledge transfer from FM to design (Jensen, 2012, p. 172):

1. codification of knowledge from building operation, which can increase awareness among designers, and is captured into knowledge repositories;
2. competency among facility managers, which can increase awareness among designers;
3. power to ensure that designers take building operation considerations seriously by using the competency of facility managers; and
4. power to ensure that codified knowledge from building operation is used by the design team.

Helle Lohmann Rasmussen, a collaborator of Jensen, similarly proposes a range of hybrid solutions for improving FM integration in AE-design (Rasmussen, 2020; Rasmussen et al., 2019). Rasmussen et al. (2019, p. 803) review the literature and identify 31 initiatives to support the transfer of knowledge from existing buildings to the design and construction of new buildings. In this context, they describe the term initiatives as covering tools, concepts, and tasks that are recommended in the literature for use by building clients in early design stages of a new facility. These initiatives include things such as “continuous briefing”, “demand of storage and workshop facilities”, and “technical due diligence”. These 31 initiatives were then used as the basis for a case study at a Danish University which then identified 11 new initiatives. The list of new initiatives includes a range of hybrid solutions for facilitating FM involvement in early stages of a facility design. However, the study’s primary finding is that the use of “initiatives does not necessarily contribute to better performance of new built facilities” (p. 810). The paper further differentiates between initiatives that are well implemented and those that have limited implementation. The authors concluded that “it takes deliberate effort to get the initiatives well implemented and fully adopted…to achieve good effect” (p. 810).

In subsequent research undertaken in Denmark, (Rasmussen, 2020) finds that project managers implemented knowledge integration tools in unique and different ways. She suggests this makes research into the use of tools to integrate operational knowledge into design problematic. She proposes that it may be more beneficial to investigate how a tool is used, rather than whether it is used. She concludes the paper by suggesting that research in this area focus less on developing new tools and the barriers to implementing them, and rather focus more on *why* the consideration of FM/O knowledge and experience is not a greater concern to AE designers and project managers of building projects. This view runs counter to the majority of other papers reviewed in this literature review, which focus on either the barriers to FM knowledge integration, or tools and mechanisms to facilitate such integration. Rasmussen suggests a lack of integration is not due to a want of tools or mechanisms, but rather due to a lack of priority.

Based on parallel mixed methods studies conducted in the UK, Singapore, and Sri Lanka, Wong et al. (2014) suggest a hybrid approach for promoting better AECFM project team integration. They propose three focus areas: 1) The development of new organisational and management structures where design and construction (DC) and FM/O teams are more structurally integrated so that periodic meetings and multiple project levels can be systematically arranged; 2) The fostering of a culture of team building and providing additional means of communication outside of structured meetings; and 3) The development of tools or infrastructure to handle better information transfer between DC and FM/O. They ultimately suggest the development of common databases and web application content management software.

Boge et al. (2018) similarly suggest the development of new tools to aid communication between FM and AE-design. Based on a survey of 837 Norwegian architecture, engineering, and real estate management industry professionals, Boge et al. (2018) find that building owners and users who wish to see successful facility management operation post-occupancy should include FM on the agenda of early phase planning meetings. They also suggest there is a need for good decision support and communication tools for building design and construction projects.

Kalantari et al. (2017a); Kalantari et al. (2017) suggest the need for new tools and methods of communication. Based on interviews and surveys of facility managers in the US, UK, and Middle East, Kalantari et al. address opportunities to better integrate FM and design by suggesting that FMs are unable to “adequately share the knowledge with designers” and that “better knowledge management software could be a useful tool to improve this situation” (Kalantari et al., 2017, p. 464). They also found that while many FM firms maintained their own databases of lessons learned, the information was not in a format that could be easily shared with designers. This, in part, led them to conclude, “it is strongly recommended that more attention should be paid in future research to exploring how BIM programs can be adjusted to provide a common and accessible platform for both FMs and designers” (Kalantari et al., 2017, p. 464).

Fatayer et al. (2019) survey the FM departments of 13 public universities in Saudi Arabia to evaluate the early involvement of FM in design development and review stages. Based on their findings, the authors recommend six activities to achieve better integration between FM and building design teams:

1. Raise awareness of the significance of maintainability through seminars and workshops showcasing best global practices. They further suggest the formation of new professional organisations to encourage such integration.
2. Take maintainability into account in schematic design stages.
3. Establish direct contact between FM departments and AE-design teams to facilitate effective communication.
4. Facility managers should become more aware of design activities and processes.
5. Develop collaborative AE and FM databases based on previous maintenance issues related to design defects. (They suggest this is because AE-design professionals are in the best position to translate operational insights into appropriate design solutions.)
6. Have design professionals return to projects they have previously designed to assess the performance of those facilities.

In a case study of eight hospital projects in Norway, Støre-Valen (2021) finds that FM involvement in all stages of a project is beneficial, however, it is particularly valuable when

FM becomes part of the design team and are physically located in the same place. The author further suggests that a “service design” approach to AE-design in which end-users and stakeholders are involved in the design process is beneficial with FM in AE-design processes. In addition, Støre-Valen finds that “dialogue meetings” and design review meetings with FM/O personnel are valuable, cost effective measures for including FM/O considerations in design phases. She further suggests the use of dialogue meetings should be further developed and tested. In conclusion, Støre-Valen notes that while BIM in FM is expected to provide future solutions that help improve the storing and sharing of FM information, its use was not implemented in any of her case studies.

Technical Proposals:

Y. Wang et al. (2013) propose a BIM-based framework to increase the consideration of FM knowledge and experience in design phases. They propose that through such a framework, facility managers could provide post-occupancy feedback to design teams. Working on a case study in China, they demonstrate a BIM framework that integrates FM work into early design phases to plan a facility manager’s maintenance plan and travel path. While Wang et al. suggest their framework integrates FM into early design phases, the working prototype appears to be more focused on accommodating FM operation and maintenance needs in their design instead of sharing FM knowledge with design.

Oti et al. (2018) proposes a framework for a BIM based feedback loop that enables the learning from past building performance by providing feedback at appropriate stages in a project’s lifecycle. They propose that feedback loops from operations to design can be “established by incorporating building management system (BMS) data into a federated BIM to inform the designer and facility manager” (196). However, the authors recognise that while there is a perception that AE and FM industries are going to benefit from an availability of large amounts of data, the automated collection, analysis, and integration of such data are problematic. This researcher suggests their proposed framework is further hindered by research which shows a slower uptake and lower levels of BIM use in FM/O industries when compared to AE-design teams (Dixit, Venkatraj, Ostadalimakhmalbaf, Pariafsai, & Lavy, 2019; Edirisinghe, London, Kalutara, & Aranda-Mena, 2017).

Based on a survey of AECFM professionals in the US, Liu and Issa (2016) note that while every project has unique characteristics, there is a large portion of the body of knowledge (BOK) that can be reused from project to project as general knowledge. Based on their research findings, they propose a BIM-FM database to document maintainability problems and concerns. They further suggest this database can be updated across the buildings lifecycle and that when maintainability problems are found that are not project specific, they can be added to the database for use on future projects, thus reducing the likelihood that similar mistakes happen again. In this matter, using BIM, it would be possible to collect information once and then use it across the whole life cycle of a facility, or new facilities. Liu and Issa (2016) also note that while FM involvement in early design phases has been shown to be valuable, FM teams are not always in existence during design phases. They propose that this can be addressed by using their proposed database to acquire an FM team's general knowledge requirements.

Liu and Issa acknowledge that their survey reflects a focus on US practice and that it would need to be carried out in other countries to expand its generalisability. In this author's opinion, the proposed BIM-FM database is further limited by its focus on maintainability issues only, such as access to equipment. It also is dependent on FM use of BIM, and like the framework proposed by Oti et al. above, it would require improved BIM competencies within FM/O.

Based on a quantitative study using a database of 39,093 work orders from the US Air Force Computerised Maintenance Management System (CMMS), Weeks and Leite (2021) propose that a CMMS can be used as a data source of information for review by design teams to improve knowledge transfer from FM to AE-design . The authors propose that by using historical work orders, actual deficiencies and their true costs can be used to help motivate owners, clients, FMs, and designers to better incorporate maintainability into early planning and design stages. While Weeks and Leite's proposal overcomes some of the limitations of BIM based frameworks discussed above, by utilising data from work orders generated by a CMMS already in use by the facility managers, it focuses on maintenance (preventative and corrective) issues only and ignores other areas of FM knowledge and information they may be able to provide input on, such as space planning, health and safety, security, or occupancy and use rates.

Hassanain et al. (2014a) highlight the significance of providing maintenance feedback to AE-design teams during design phases. In doing so, they identify a range of significant architectural mechanical system (HVAC) defects they attribute to lack of feedback from OM to AE-design teams during design development and review stages (Table 2.11). Based on their findings they propose a set of guidelines and checklists to be considered by AE-design teams at 30%, 60%, and 90% design completion (see also, Hassanain et al., 2014b).

Table 2.11: Common design defects attributed to lack of FM involvement in design

Common Building Design Defects Attributed to Lack of FM Involvement in Design Phases	
Architectural Defects	**HVAC Defects**
1. Inability to maintain vertical risers due to limited areas of service shafts.	1. Inadequacy of the HVAC system to provide the required comfort zone temperature.
2. Signs of stains and seepage due to improper rainwater drainage around windows.	2. Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air.
3. Signs of stains and seepage due to improper rainwater drainage around windows.	3. Propagation of foul smells due to lack of provision of exhaust fans in kitchens and toilets.
4. Wall edges that could chip due to impacts of loads and occupants.	4. Overheating of the building due to shutdown of chillers for maintenance or replacement of any parts.
5. Insufficient availability of specific building materials in the market when replacement of the same is required.	5. Water spillage from HVAC units due to lack of condensation drainage systems.
6. Inappropriate selection and specification of specific building material for incorporation in the project	6. Noisy air-handling units due to lack of proper insulation.
7. Inability to entirely reach and maintain fenestration due to the architectural form of the building.	7. Inability to reach and maintain chillers, cooling towers and condensers due to the location of the mechanical plant.
8. Plaster decay on external wall surface due to dampness.	8. Signs of biological stains on false ceilings caused by leaky HVAC ducts.
9. Moisture and vapour travelling from wet to dry faces.	9. Inability to reach and maintain condensation pan locations.
10. Difficulty in moving furniture and equipment within interior spaces due to limited width and height of doors.	10. Moisture condensation on walls and glass due to inappropriate HVAC design temperature.
11. Propagation of foul odour due to placement of kitchens and toilets in the direction of prevailing wind.	11. Overcooling of the building due to temperature difference between the supply and return chilled water during winter.
12. Design and placement of large windows in building elevations facing the solar path and wind direction.	12. Static electricity due to insufficient humidification of admitted air to the building.
13. Visibility of signs of stains and development of moulds due to inadequate means of ventilation (natural or mechanical or a combination of both).	
14. Paint peeling, flaking, blistering, biological attack, and efflorescence.	
15. Specification of dark colour paint as an exterior finish in hot, arid, and dusty regions.	
(Hassanain et al., 2014a, 2014b)	

2.4.1.1 Summary of FM – AE Integration Proposals

In summarising efforts to facilitate improved FM involvement in AE-design, these proposals have been categorised, based on the discussion in Section 2.3.1, as being grounded in *technical* issues, *social* factors, or a *hybrid* of both (Table 2.12). In keeping with the analysis from Section 2.3.1, these proposals are further classified by the type of barriers they seek to address: lack of resources, a knowledge gap, the nature of the design process, and a lack of priority or incentive.

Table 2.12: Summary of proposals to promote FM integration in AE-design

Summary of Proposals to Promote FM-Design Integration – Select Authors				
Factor	**Barrier**	**Proposals**	**Proposal Classification Rationale**	**Referencing Authors**
Hybrid	Lack of resources	Improve communication between designers and FMs	References to improved communication refer to both improving interpersonal communication between team members and to improving tools and technologies.	(Fatayer et al., 2019; Kalantari et al., 2017a; Kalantari et al., 2017; Meng, 2013; Wong et al., 2014)
Hybrid	Lack of resources	Codification of FM knowledge	Refers to both the categorisation of individual and organisational knowledge as well as tools to store and transmit that knowledge.	(Jensen, 2012; Jensen et al., 2019)
Hybrid	Knowledge gap	Improve existing practices	Literature refers to both the improvement of interpersonal practices and relationships as well as the better use of existing tools and technologies.	(Liu & Issa, 2016; Rasmussen, 2020; Rasmussen et al., 2019)
Hybrid	Lack of resources / Knowledge gap	Increased use of POE	Increased use of POE relies on improved interpersonal interactions of building occupants and better tools to make easier use of knowledge gained from POEs.	(Göçer et al., 2015; Menezes et al., 2012)
Social	Lack of priority or incentive / Nature of design process	Require FM integration	Generally, refers to greater emphasis placed on the role of FM through improved interpersonal relationships or focus.	(Jensen, 2012)
Social	Knowledge gap	Increase awareness of significance of maintainability and value of FM		(Fatayer et al., 2019; Meng, 2013)
Social	Nature of design process	Create defined role for FM on design team		(Meng, 2013; Mohammed & Hassanain, 2010)
Social	Nature of design process	Redefined design/construction framework that includes FMs		(Erdener, 2003; Loosemore & Chandra, 2012)
Social	Knowledge gap	Improve FM competencies	Literature suggests FMs have knowledge gaps and need additional training.	(Jaunzens et al., 2001; Jensen, 2012; Meng, 2013)
Social	Nature of design process	FM design reviews	The AE-design process traditionally does not include a defined role in the design process for FMs. Similarly, FMs are often not included in design review or planning meetings.	(Edum-Fotwe et al., 2003; Hen et al., 2021; Støre-Valen, 2021; Weeks & Leite, 2021)
Social	Nature of design process	Involve FM in design process (general)		(Boge et al., 2018; Meng, 2013; Y. Wang et al., 2013)
Social	Nature of design process	Include FM in briefing		(Chandra & Loosemore, 2011; Hen et al., 2021; Jaunzens et al., 2001; Jensen, 2012)
Technical	Lack of resources	Use of technology and software to make data from past projects easily accessible	Literature refers to the development of specific tools, software, or technology to promote increased FM integration in design.	(Bröchner, 2003; Emmitt, 2007; Jensen et al., 2019; Liu & Issa, 2016; Weeks & Leite, 2021; Wong et al., 2014)
Technical	Lack of resources	IOT and databases to act as a repository of institutional knowledge/Shared knowledge database		(Anh Thi Lê & Brønn, 2007; Fatayer et al., 2019; Jensen, 2012; Jensen et al., 2019; Liu & Issa, 2016)
Technical	Lack of resources	BIM platforms to transfer data between FM and design		(Göçer et al., 2015; Jensen, 2012; Jensen et al., 2019; Liu & Issa, 2016; Oti et al., 2016; Støre-Valen, 2021; Y. Wang et al., 2013)
Technical	Lack of resources	Checklists/guidelines for design teams		(Hassanain et al., 2014a, 2014b; Hassanain et al., 2015, 2016; Jensen et al., 2019)
Barrier classification by author				

This literature review finds multiple benefits of, barriers to, and proposals for promoting improved FM-AE information and knowledge sharing. Based on the summary of proposals discussed above, the researcher further summarises and categorises the findings from the literature review into five consolidated categories of proposals for promoting FM knowledge sharing with AE-design, identified in Table 2.13.

Table 2.13: Proposals to promote FM-design integration reviewed

Suggested Proposals to Promote FM-Design Integration	
Suggested Proposal	**Proposal Category**
1. Codify FM knowledge	Hybrid
2. Create a defined role for FM in the design process or on the design team	Social
a. Include contract requirements to include FM in design	Social
b. Conduct regular design review meetings with FM	Social
3. Improve FM competencies through better training	Social
4. Improve communication between designers and FMs	Hybrid
5. Use technology to make data from past projects more accessible and shareable	Technical
a. Improve FM knowledge management software	Technical
b. Use IOT and databases to act as a repository of institutional knowledge	Technical
c. Use BIM, GIS, or platforms to transfer data between FM and design teams	Technical

This thesis does not intend to validate or promote one of the identified conceptual approaches over another as preferred or ideal. Each approach may be seen as a reasonable solution to improving FM involvement and knowledge sharing with AE-design in their own context and time – social, technical, or hybrid socio-technical approaches may all be viable. However, it is noted that within this review multiple researchers propose that BIM represents an ideal solution for promoting increased knowledge sharing and involvement of FM in building design processes. This is seen to the researcher as a contradiction of sorts as a technological knowledge and technical skills gap within FM is also seen as a barrier to FM involvement with design. Additionally, other researchers have found barriers limiting FM's use of BIM (such as Al-Kasasbeh, Abudayyeh, & Liu, 2021; Codinhoto, Donato, Comlay, Adeyeye, & Kiviniemi, 2018; Edirisinghe et al., 2017; Munir, Kiviniemi, Finnegan, & Jones, 2019). (BIM is further discussed in the context of this thesis in Section 2.10 below.)

Notwithstanding this contradiction, the use of BIM as a proposal to promote FM involvement in design fits within the codification of knowledge proposal identified by Jensen (Jensen, 2009, 2012; Jensen et al., 2019). According to Jensen (2009), knowledge codification from building operation can take many forms. Facility management organisations often utilise computer-aided FM systems (CAFM) or building management systems (BMS) that collect information from building operations on a continuous basis. By collecting this information, valuable facility operation data can be provided, such as space utilisation, operational costs (such as maintenance and cleaning), or energy consumption. Furthermore, many CAFM systems can generate key indicators based on historical data. However, despite this data collection, Jensen suggests there is a significant amount of unused FM data within such systems that could be useful in transferring knowledge from FM to design, if the appropriate resources were available to retrieve, analyse, and codify it.

Jensen further notes this codification of FM data for use by designers represents one of the promising developments in relation to the comprehensive use of BIM models, which are used to facilitate the digital transfer of building design and construction documentation to FM and building operations. However, according to Jensen, such knowledge transfer typically represents a transfer of information *from* building design *to* building operation, rather than a transfer of information *from* building operation *to* design. Jensen (2009, p. 134) also asserts with future development of BIM “it will be possible to generate briefing information from BIM based on an ongoing update of experience from the operation of existing buildings.” While Jensen specifically refers to briefing generation, such a system could likewise be used to inform design decisions through BIM-enabled knowledge, information, and data transfer *from* FM to design teams (Jensen et al., 2019).

Jensen’s conclusion also fits within those of other researchers who suggest improvements in information technology will support FM involvement in design (Anh Thi Lê & Brønn, 2007; Bröchner, 1996; Emmitt, 2007; Fatayer et al., 2019; Jensen et al., 2019; Liu & Issa, 2016). Furthermore, it fits with the findings of other researchers, such as Göçer et al. (2015), Liu and Issa (2016), Oti et al. (2018) or H. Wang, Meng, and McGetrick (2018), who propose BIM based communication platforms may lead to increased quantitative data sharing. However, these researchers have generally found gaps in the tools and methods necessary to transfer knowledge effectively and efficiently in a meaningful way between FM and design teams. When taken together, these views also suggest opportunities to examine the potential for information technology and databases to act as repositories of FM knowledge and communication vehicles that integrate FM knowledge with design.

2.4.2 Section Conclusion

The review of the literature which informed Chapter 1, and Chapter 2, up to this point, surveyed the domain of facility management and found widespread consensus regarding its multi-faceted nature. Modern facility management is not limited to the operation and maintenance of a facility. Instead, it is also concerned with strategic planning and user experiences. This review also finds that while the role of facility management should not be confused with that of design, FMs are strategically positioned to play a valuable role in facility design. Facility managers also have an intrinsic interest in the design of their facilities as the quality of facility design directly impacts the ability of facility managers to fulfil their professional responsibilities effectively. Additionally, FMs have an impetus to increase their involvement in design as modern buildings often experience performance gaps between anticipated and actual operational performance, which are often blamed on FMs.

The involvement of FMs in early design has been found to be valuable for two reasons: 1) operational difficulties are often caused by design faults rather than faults in construction, and 2) the effects of early design decisions have been shown to have far-reaching impacts on the functionality, operation, and maintenance of built assets – particularly with regards to cost. However, prior research has found persistent barriers which limit the sharing of FM involvement in AE-design processes. The research reviewed found these barriers persistent both temporarily, over the 20 years of papers reviewed, and geographically, across a broad range of countries and contexts. In the scope of this review, the author categorised these barriers as based on the following factors (Table 2.5):

1. Lack of resources and tools
2. Knowledge gap
3. Nature of design process
4. Lack of priority or incentives

It is noted that these barriers are broad in their nature and are based on a range of social, technical, and hybrid factors. This range of factors seemingly makes the barriers challenging to address, as evident by their persistent recognition within the research. In seeking to address these barriers, a range of proposals have been offered by other researchers. These proposals are similarly broad and on one hand are based on social, cultural, organisational theories (social) for guidance on how to support knowledge and information sharing from FM to AE. On the other hand, many authors have proposed technical solutions based on rationale, engineering frameworks to support knowledge and information sharing (technical). In addition, some researchers offer hybrid solutions that rely on both social and technological frameworks for answers on how to facilitate FM knowledge sharing best. These proposals were identified in Table 2.12 and summarised by this author as:

1 Codify FM knowledge.
2 Create a defined role for FM in the design process or on the design team.
3 Improve FM competencies through better training.
4 Improve communication between designers and FMs.
5 Use technology to make data from past projects more accessible and shareable.

While this research categorises these proposals, and related barriers, as social, technical, and hybrid, the reality is that many of the tools and frameworks developed span multiple categories and depend on each other. Even strictly social proposals are somewhat dependent on technology to enable their implementation and vice versa. For example, BIM proposals, such as those offered by Liu and Issa (2016) or H. Wang and Meng (2021), would rely on the codification of FM knowledge. Furthermore, proposals based on improving communication between FM would require a role for FM in the design process for their knowledge to be communicated and received. Therefore, while these proposals are listed individually above and in Table 2.12, strict independence between them is not seen as universal.

The range of proposals offered by other researchers is not surprising as neither AE-design nor FM/O represents standardised and uniform practices. Every building design project and every building design operation is unique in some ways. Furthermore, each country has its own ways of practice, which presents an opportunity to further examine these issues within the community of professionals defined in the scope of the research.

This author recognises that this summary of proposals is based on his literature review and may not be all-encompassing. There is reason to believe that other proposals or related tools exist that were not captured in the literature review. For example, other works may not have been identified due to how their corresponding authors identify them or how the keyword searches were performed for this research. Additionally, other research areas might be looked to for opportunities for FM to be more involved in AE-design. For example, alternative approaches to contract or project delivery, such as Integrated Project Delivery (IPD), may be looked to; although, such methods are broader than the scope of this research. However, through the examination of prior research related to the barriers to and proposals for supporting FM involvement with AE-design, this literature review provides a foundation for subsequent data collection phases of the research and examination of the aim and objectives defined within the scope of this study.

While this marks the end of this section of the literature review, the author recognises that many fields can provide insight into the barriers limiting knowledge transfer from FM to AE and how to potentially overcome those barriers. Therefore, additional insight may be provided by looking to other research areas, other fields of study, or other industries for inspiration and possible recommendations.

2.5 Working Definitions of Data, Information, and Knowledge

As this thesis is focused on the sharing of information and knowledge between FM and AE-design teams, it is necessary to briefly define and distinguish the terms data, information, and knowledge as used in this thesis. There are many discussions of the differences between data, information, and knowledge (such as Ackoff, 1989; D'Alfonso, 2013; Liew, 2013; Rowley, 2007; Spence, 2011; Zins, 2007); however, this thesis uses definitions provided by Liew (2007, p. 5) as a basis for defining data, information, and knowledge for use in this thesis:

> **Data** represents raw, unstructured recorded (captured and stored) symbols and signal readings, which include words (text and/or verbal), numbers, diagrams, and images. The main purpose of data is to record activities or situations that attempt to capture true pictures of real events.
>
> **Information** is data in context. Information contains relevant meaning, implication, or input for decision and/or action. Information comes from both current and historical, processed data. The purpose of information is to aid in making decisions and/or solving problems or realising an opportunity.
>
> **Knowledge** is the (1) cognition or recognition (know-what), (2) capacity to act (know-how), and (3) understanding (know-why) that resides or is contained within the mind. Knowledge can be seen as actionable information.

Data, information, and knowledge are further differentiated by Kamaruzzaman et al. (2018) who suggests, “Data alone has no context. When it is put into context, it becomes information. When the connections are made between different pieces of information, forming patterns, knowledge is obtained” (Figure 2.2).

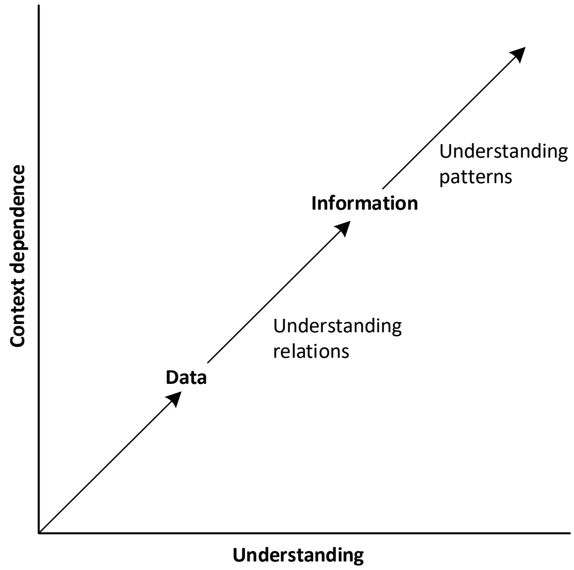


Figure 2.2: The relationship of context to understanding
(adapted from Brelade & Harman, 2003; Mirarchi et al., 2018)

Quigley and Debons (1999, as cited in H. Wang et al., 2018) additionally differentiate the difference between information and knowledge by conceptualising them as answers to *when, where, who,* and *what questions* (information), versus *how* and *why* questions (knowledge). Where information pertains to a collection of facts or data about a thing that have been organised to have meaning, knowledge requires an awareness, understanding, and familiarity gained through learning and application to a problem (Easterby-Smith & Lyles, 2011; Rainer, Prince, Splettstoesser-Hogeterp, Sanchez-Rodriguez, & Ebrahimi, 2020). For this reason, H. Wang et al. (2018) place knowledge at a higher level than information, and suggest they can be arranged in a hierarchy in which data is placed at the bottom and knowledge at the top.

Taking a somewhat contrarian view, Alavi and Leidner (2001, p. 8) suggest knowledge and information are not significantly different concepts, and that the two flow back and forth. They propose “Information is converted to knowledge once it is processed in the mind of individuals and knowledge becomes information once it is articulated and presented in the form of text, graphics, words, or other symbolic forms.”

According to Chandra and Loosemore (2011), knowledge can be viewed as structured information and information in context. The definition and understanding of knowledge, therefore, varies by context. This view is reflected by Von Krogh, Nonaka, and Aben (2001) who refer to concepts of knowledge domains when defining knowledge. They describe a knowledge domain as consisting of "relevant data, information, and articulated knowledge" concerning a particular subject. Sainter, Oldham, Larkin, Murton, and Brimble (2000, p. 2) further describe knowledge as the "experience, concepts, values, beliefs, and ways of working that can be shared and communicated." Sunnersjö (2010) further contextualises knowledge and describes it as understanding the content, origins, and applicability of given information.

When these definitions are applied to the building design process, the data, knowledge, and information that help inform AE-design decisions can come from many sources; however, the sharing of knowledge and information between FM and AE designers is the focus here.

2.6 Working Definition of Design – Introduction

This thesis is based on the fundamental premise that facilitating knowledge and information sharing between FM and AE-design teams will enhance the building design process. This understanding is based on established research that finds the involvement of FM in early design phases positively impacts the outcome of the AE-design process (See Chapter 1, Section 1.2.5). However, if one is to develop solutions that facilitate information sharing between FM and AE-design, those solutions must be informed by an understanding of design. Furthermore, according to Pikas, Koskela, and Seppänen (2020), in order to advance building design practices, it is necessary to first understand the conceptual nature of design. To this end, the thesis follows the guidance of Maher and Gero (2012), who propose it is through a better understanding of design that we can reflect and improve the design process, "rather than to assume it is a magical quality of special people."

In seeking to understand design in a broad sense, the author proposes it is not necessary to specifically focus on design as it relates to the built environment; instead, design may be examined holistically. And while colloquially design often refers to the physical appearance, or styling, of an object, the term's proper meaning goes beyond that. It is this deeper meaning explored here (Stickdorn, Schneider, Andrews, & Lawrence, 2011).

2.6.1 Design Methodology, Method, Model, Processes, Artefact, and Object

Before reviewing design as a field of inquiry and establishing a definition of design for use in this thesis, it is necessary to briefly discuss and define key terms and concepts associated with the act of design:

> **Design Methodology(ies)**: Often refers to the study of design as a discipline and the relationship between design, science, and practice.
>
> **Design Method**: A conceptual framework or basic structure that underlies a more complex system, in this case, a design system that is applicable across a range of disciplines (Maher & Gero, 2012; Plowright, 2014).
>
> **Design Model**: In contrast to design methods, which may be seen as providing a systematic approach to design, design models provide "abstractions of design processes, design knowledge, and the representation of design artefacts" (Maher & Gero, 2012, p. 117).
>
> **Design Process**: A series or sequence of design "steps taken to arrive at a conclusion" (Plowright, 2014, p. 2).
>
> **Design Artefact**: Refers to the outcome of a design effort but is not necessarily the design object itself. It may be seen as a plan for the construction of a design object, such as an architect's building plans (as opposed to a completed building) or the plans and specifications for an industrial product (Ralph & Wand, 2009).
>
> **Design Object**: The object being designed. In the context of architecture, it may be seen as the building after construction. Or a car in which we drive, but not the plans and specifications which led to the construction process (Ralph & Wand, 2009).

2.6.2 Design, the Science of Design, and Design Science

It is also important to clarify the epistemological and ontological realms in which the term design is examined. In doing so, it is vital to make a clear distinction between *design science research* (DSR) as a research strategy (the research strategy used in this thesis), *design science* as a conceptual approach to design in systematic and scientific terms, and the *science of design,* in which design is seen as the focus of an empirical mode of inquiry.

The concepts of these terms are distinct in their meanings but are often used interchangeably in academic literature. For example, some authors equate the terms *science of design* with *design science* (or view them as very similar concepts), while others view them as fundamentally different concepts. Cross (2006) acknowledges this confusion and finds that despite multiple attempts to clarify the matter, confusion about the *design* and *science* relationship persists. This confusion led Cross to definitively state, "let us be clear that a 'science of design' is not the same as a 'design science'" Cross (2006, p. 99). This section articulates the differences between *design science research, design science,* and the *science of design* as understood in this research.

Buckminster Fuller is recognised as the first to use the term *design science* (Cross, 2006; Maher & Gero, 2012). The term was later adapted by Gregory (1966) for the 1965 conference, *The Design Method*. In doing so, Gregory distinguished the *scientific method* and *design method*. Gregory made clear that he viewed *design* as separate from *science* and that *design science* was a reference to the *scientific study of design*. Following these initial uses of the term, Simon's 1969 publication of The Sciences of the Artificial established a basic understanding of *design science* (Simon, 1996). According to Maher and Gero (2012, pp. 114-115), Simon's book set off a debate over whether design is itself a science and should be practised as such, following established scientific methods. Maher and Gero also suggest Simon's work led to dual understandings of the term *design science*:

1. **Science of Design** – the study of design that represents a body of knowledge that uses scientific methods to improve our understanding of the process of design, what designers think, et cetera. (Cross, 2006; Gasparski & Strzalecki, 1990; Gregory, 1966; Maher & Gero, 2012) This view is often defined as design research (Cross, 2007); and
2. **Design Science –** The belief that design as a practice can be practised, improved, and further developed using scientific methods. This represents a systematic view of design similar to the scientific method (Hansen, 1974 as cited in Cross, 2001; Cross, 2006; Maher & Gero, 2012).

In their work, Maher and Gero (2012, p. 114) add to the confusion of the terms by stating, "design science takes a scientific approach to understanding what designing is and how designers think." While using the term *design science*, this reflects the theoretical construct typically reflected in the view of the *science of design* stated above and championed by Cross. However, in the next sentence, they return to a *design science* construct. They say: "Advances in design science occur through the development of theories, models, and methods of designing." This seems to refer to the development and application of universal or scientific principles of design. Maher and Gero further express:

> The assumption underlying design science is that there are commonalities and regularities in all designing independent of the discipline and independent of the specific artefact being designed, and that these regularities are generalisable across the individuals that are designing and creating new artefacts. That is, designing, whether architectural design, mechanical engineering design, textile design, software design, interface design, or legislation design, has theories, processes, and methods in common. (p. 114)

According to Maher and Gero (2012, p. 115), this view of *design science* works from the assumption that design can be understood as a discipline in its own right, and attempts can be made to understand it independent of the object being designed, which represents a *design science* perspective. In the end, Maher and Gero seem to combine the historical understandings of the terms *design science* and *science of design* into a single construct and then stick with the term *design science*. They see *design science* as operating within an understanding of design that sees it as a distinct field of study that can be understood independently of the object being designed, but they also acknowledge Cross's view of the s*cience of design* that represents a body of work which seeks to improve our understanding of design. They ultimately lump the two ideas together and define *design science* as a broad field of study that encompasses "*several areas of study in understanding design*." In doing so, it is evident that Maher and Gero have accepted that the term's usage has evolved to the point where it encompasses both meanings. This runs counter to the view of Cross (2006) that the *science of design* is not the same as a *design science*.

The view expressed by Cross, the *science of design* construct, has seen widespread development in the ideas of many others (C. Alexander, 1984; Buchanan, 1992, 2001; Buchanan & Margolin, 1995; Lawson, 1994, 2005; Rowe, 1994), and is generally the accepted definition of Simon's (1996) original term *design science.* Within this understanding of the *science of design*, Cross (2006) suggests there are three areas of focus. While he uses the term *design research* in this context, he situates *design resear*ch within the *science of design*. Cross (2006, p. 101) proposes a taxonomy focused on the categories of people, process, and products, which include the areas of:

1. **Design epistemology –** the study of designerly ways of knowing;
2. **Design praxiology** – the study of the practices and processes of design; and
3. **Design phenomenology** – the study of the form and configuration of artefacts.

Within these diverse contexts, this thesis operates with the following understanding of the terms in question:

1. **Design Science Research (DSR)** – represents an outcome-based research methodology or strategy and does not refer to a scientific or systematic approach to design;
2. **Science of Design** – represents research into the methods and practices of design. This accepts a broad understanding of the term and is akin to the *design science* view of Maher and Gero (2012). However, to clarify and reduce confusion with the *design science research* methodology, this view is described as the *science of design* in this thesis.
    a. Design in this context represents an object of inquiry within the *science of design* and will be further defined below.

It should be noted that while DSR may be used as one of the multiple research strategies through which *design,* as a focus of inquiry is examined within the *science of design*, the terms should be understood independently and with distinct meanings. Furthermore, a strict definition of *design science* as a universal, scientific, and systematic approach to the process and methodology of *design* is viewed as a historical artefact and is not adopted.

2.6.3 Definitions of Design

Ralph and Wand (2009, p. 1) find there is no "generally-accepted and precise definition of design as a concept" (see also Pikas et al. (2020) and Dilnot (2018)). Buchanan (2001) suggests that one of the greatest strengths of design is that there is no established, single definition.

To Buchanan, fields of inquiry in which definitions are universally understood are stagnant, and no longer offer challenges to *accepted truths*. In this view, Buchanan suggests one of design's strengths is the inability to reach a consensus regarding what design is or what the term means.

Taking an alternative view to that of Buchanan, Freeman and Hart (2004) identify the need for a comprehensive and systematic research effort into the *science of design*. Furthermore, according to Ralph and Wand (2009), by reaching a consensus definition of the concept of design, a model may be generated that conceptually links design projects. This definition may then be used to classify design knowledge, and the accompanying conceptual model used to classify various approaches to design. Out of this process of defining design as a concept, Ralph and Wand (2009, p. 2) identify several benefits:

1. From a research perspective, through theoretical or empirical work in which design is a construct, a clear definition helps ensure construct validity.
    a. A clear understanding of the meaning of design facilitates the development of measures for evaluating design-related constructs, such as design success (or the ability to assess design quality better).
2. A cumulative tradition of design research can benefit from a well-accepted definition of design, the alternative being different theories defining design differently or not at all. A clear description of design can help organise, share, and facilitate the reuse of design knowledge.
3. Understanding the elements of design helps determine the issues and information relevant to the process of design and in planning this process.

This thesis proposes that there is value in reaching a clear definition of design to help guide the scope of the research, and in the following sections, reviews prior efforts to do so. It then suggests a working definition of design that provides a foundation for this research study.

According to Asimow (1962, p. 64), design represents "Decision making in the face of uncertainty, with high penalties for error." Meanwhile Simon (1996, p. 111) defines design as a series of rational procedures that respond to a well-defined problem, stating, "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones.” Simon further elaborates, “The engineer, and more generally, the designer is concerned with how things ought to be — how they ought to be to attain goals and to function.” Simon’s view is recognised as a neo-positivist view of design and, according to Buchanan (1992), is one of the most influential and longest-lasting views which came out of the neo-positivist era of design.

Writing in response to views such as Asimow’s and Simon’s, Buchanan (1992) argued that early conceptualisations of design viewed it as a linear process in which determinate problems have definite conclusions. In contrast, the problems addressed by designers, in practice, do not yield to a linear analysis or synthesis. Buchannan then links design problems to the views of Rittel and Webber (1973) who argue most problems faced by planners (or designers) can be described as wicked problems. Rittel and Webber describe wicked problems as a “class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing” (as described in Churchman, 1967, p. 141).

Rittel and Webber originally conceptualised wicked problems in relation to planning and public policy concerns. However, the concept was quickly applied broadly to general design processes due to design's open-ended, problem-solving nature (Buchanan, 1992; Hocking, Brown, & Harris, 2015; Kpamma, Adjei-Kumi, Ayarkwa, & Adinyira, 2017). According to Rittel and Webber (1973, p. 160), in planning, “problems are wicked problems instead of ‘tame’, single disciplinary, problems of science.” Rittel and Webber further identify key differences between tame problems and wicked problems. In tame problems, the mission is typically clear. Similarly, it is clear whether the problems have been solved, where wicked problems lack such clarifying traits. According to Rittel and Webber (1973, pp. 161-166), there are ten key components of wicked problems:

1. There is no definitive formulation of a wicked problem;
2. Wicked problems have no stopping rule;
3. Solutions to wicked problems are not true-or-false, but good-or-bad;
4. There is no immediate and no ultimate test of a solution to a wicked problem;
5. Every solution to a wicked problem is a “one-shot operation” because there is no

opportunity to learn by trial-and-error, every attempt counts significantly;

6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan;
7. Every wicked problem is essentially unique;
8. Every wicked problem can be considered to be a symptom of another problem;
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution; and
10. The planner has no right to be wrong.

Rittel and Webber's view of wicked problems, when viewed through the lens of the design process, suggest indeterminacy is a fundamental aspect in all but the most basic planning or design problems. In contrast, because of their indeterminacy, Buchanan concludes that design problems have no definitive conditions or limits (Buchanan, 1992). Buchanan takes a pluralist view of design that similarly reflects the view by Papanek (1985) that:

> …design as a problem-solving activity can never, by definition, yield the one right answer: it will always produce an infinite number of answers, some 'righter' and some 'wronger.' The 'rightness' of any design solution will depend on the meaning with which we invest the arrangement. (pp. 5-6)

In 1987, Rowe (1994) published the first edition of his book, *Design Thinking*, which sought to describe the methods and approaches to design used by architects and urban planners and represented an early use of the term *design thinking* as it has come to be understood in contemporary design studies. Rowe saw design as a "practical form of inquiry insofar as it is concerned with making and a certain commonplace usefulness, quite apart from its more esoteric benefits" (p. 1). He further contends that "some might maintain, design is much more than mere problem solving" depending on one's understanding of the term *problem*. Rowe felt it was hard to imagine a scenario where design, in relation to problem-solving, could not be covered by the definition of a problem by Thorndike (1913). Paraphrasing Thorndike, Rowe (1994) stated that "…a problem can be said to exist if an organism wants something but the actions necessary to obtain it are not immediately obvious" (p. 39). Rowe's work described design as a mode of inquiry.

Discussing engineering design, Braha and Maimon (1997, p. 146) similarly describe design as a problem-solving effort and state that “Design as problem-solving is a natural and the most ubiquitous of human activities.” They further suggest that design “begins with the acknowledgement of needs and dissatisfaction with the current state of affairs, and realisation that some action must take place in order to solve the problem.”

Expanding on the decision-making and problem-solving nature of design suggested by earlier researchers, Lawson (2005) suggests design is different from general problem-solving in its open-ended nature. Lawson further proposes that scientists solve problems through analysis while designers solve problems through synthesis – where alternatives are generated, evaluated, and refined against a set of project requirements. While Dickson (2004, p. 192) defined the overall design and procurement process as “a series of decisions that lead progressively towards the built reality.”

Joseph Zinter (as cited in "Designing in the human context," 2012) suggests that at its root, design is related to problem-solving and decision making by stating: “Design is about making decisions, often in the face of uncertainty.” Harputlugil (2018, p. 217) expands on this view and defines design as “an effective decision-making activity based on problem-solving.” Cross (1990 as cited in Lawson, 2018, p. 86) takes an expansive view of design and reinforces the theme of design as problem-solving; however, he adds the role of information within problem-solving:

> Designers typically produce novel unexpected solutions, tolerate uncertainty, work with incomplete information, apply imagination and constructive forethought to practical problems and use drawings and other modelling media as means of problem solving.

Atsrim, Buertey, and Boateng (2015) find a similar view regarding the importance of problem-solving and information in design when applied to the architecture, engineering, and construction (AEC) industry. They find that the definition of design depends on its context. However, they add that common to most AEC definitions of design are specific characteristics: 1) requirements, 2) creativity, 3) information, and 4) problem-solving. Their review finds the previous discussed problem solving and information characteristics of design reflected in AEC views of design.

2.6.4 Role of Information in Design

The role of information in design, and the associated view of design as an act of problem-solving is implicit in many historical definitions of design. Its role suggests an underlying factor that may have driven the transition from a *neo-positivist* view of design, such as Simon (1996), to pluralist views, such as Rittel and Webber (1973), Buchanan (1992), Papanek (1985), or Lawson (2005). This is because views such as Simon's, or the early views of C. Alexander (1964), would have required complete information or the ability to deeply process information related to design decisions to reach correct solutions. However, because designers work with incomplete information, Dorst and Lawson (2013) suggest it is difficult to evaluate the effectiveness or correctness of a design.

Authors such as Buchanan (1992), Lawson (2005), Papanek (1985), and Rittel and Webber (1973) suggest design will never lead to one correct answer. Rittel and Webber (1973, p. 163) further describe one of the clarifying features of wicked problems as the ambiguity of when the problem has been solved, as "…the answer will be normally unambiguous. For wicked planning problems, there are no true or false answers." In its most basic sense, this represents a problem of information, or more precisely, a lack of information. Furthermore, the statement by Nelson and Stolterman (2003) that we cannot know the full consequences of a design ahead of time is grounded in an inability to process or gather the necessary information. We cannot know the consequences of our design decisions because of a lack of essential information and processing limitations (in short, because of our bounded rationality – Section 2.8).

The role of information in the design process is similarly reflected in views by Ralph and Wand (2009), who undertake a detailed analysis of design definitions to establish a formal definition and conceptual model of design.

Ralph and Wand (2009, p. 4) find in their research that many definitions of design refer to "parts, components, or elements" of which design objects are composed. They refer to these sub-elements, or components, as primitives. Because all conceptual things can be said to be made up of smaller components, it can be said that all design involves *primitives*, which can be, or are, "assembled or transformed to create a design object." While not stated as such in the explanation of their definition, nor stated in the context of Dorst and Lawson (2013), it can be assumed that information represents a primitive.

In many cases, the outcome of the design process does not directly result in the manifestation of a physical design object. In fields such as architecture, the outcome of an architect's design process is a plan for construction. This suggests that design can be characterised as a planning process rather than a building or construction process. While in some design processes, the act of building may exist simultaneously or interchangeably with planning, it is this act of planning that generally specifies the design process. According to Ralph and Wand, the design process exists when the

> …agent specifies properties of the design object: sometimes as a symbolic representation, as in an architectural blueprint, sometimes as a mental representation, as in a picture in a painter's mind, and sometimes as the artefact itself, as in a hand-carved boomerang. (2009, p. 4)

Through the process of specification and attribution of goals, every design agent embeds within the design process expectations or desires for a "design object to possess certain properties or exhibit certain behaviours" (Ralph & Wand, 2009, p. 5). These properties can be understood as design requirements and are an inherent aspect of design. Similarly, all design involves constraints**.** Time and resources aside, all design operates within a setting that includes restrictions of some kind. Physical design objects must respond to the laws of physics; digital design objects must respond to the limitations of memory and computational environments. Thus, it can be said that all design exists within an environment or context (Ralph & Wand, 2009, p. 5). Using this analysis, Ralph and Wand (2009, p. 6) develop a definition of design as follows:

> **DESIGN**
>
> ***(noun)*** a specification of an object, manifested by some agent, intended to accomplish goals, in a particular environment, using a set of primitive components, satisfying a set of requirements, subject to some constraints.
>
> **(verb, transitive)** to create a design, in an environment (where the designer operates)

According to the view of Ralph and Wand, if one views design as a process, then the output of that process is the specification of a design object, and the primitives, goals, requirements, constraints, and environment can be seen as inputs into the design process. With regards to these inputs, design must begin with intentionality regarding a design object's intended environment and the type of object to be designed. If these inputs change dramatically, such as the type of object being designed, or the environment in which it will exist, the existing design effort may no longer be seen as meaningful, and a new process should begin. The role of changing information in the design process involves a process of exploration and implies that design must adjust and adapt as information is acquired during the design process. This can be understood in relation to the previously discussed concepts of information; however, while discussed in their analysis, missing from Ralph and Wand's definition above is a reference to the role of information within design and the changing nature of information throughout the design process.

In another effort to concisely define design, Parsons (2015) explores definitions of design from the viewpoint of a philosopher. According to Parsons, when philosophers seek to understand a concept, they look for a particular sort of definition, which he calls a "philosophical definition." Parsons defines a philosophical definition as one which "consists of a set of conditions that are individually necessary, and jointly sufficient, being an instance of the concept" (p. 13). This defines necessary conditions or the features any "instances of the concept must have." If one can provide a definition of a concept that can specify conditions that are each individually necessary and jointly sufficient to describe an instance of the concept, such a definition has the "special property of picking out all and only the instances of the concept." Such a definition can then describe the essence of the concept and allow us to understand a concept in a precise way. It further allows us to understand why any given instance relates to a concept or not. As an example, Parsons uses the concept of a bachelor. Being unmarried is a necessary condition for the concept of a bachelor as are *unmarried*, *adult male*, and *human*. Anything that satisfies these conditions, out of necessity, represents an instance of the concept of bachelor. Using a philosophical definition approach to defining design, through a series of steps in which he discusses and justifies each of the elements of his definition, Parsons (2015) develops the following definition:

> Design is the intentional solution of a problem, by the creation of plans for a new sort of thing, where the plans would not be immediately seen, by a reasonable person, as an inadequate solution. (p. 21)

Parsons situates his definition firmly within the context of other definitions by tying design to the act of problem-solving. However, by including the phrase "inadequate solution" in his definition, Parsons introduces a value judgement not included in other proposed definitions, such as Ralph and Wand's. While Parsons seeks to develop a philosophical definition of design that captures its essence, this inclusion of adequacy as a defining characteristic of design seems to contradict his stated aim. In contrast, in the development of a definition by Ralph and Wand (2009, p. 3), they find: "Designs may be suboptimal, but we still call them designs." This may be read as inadequate design solutions are still design solutions, which contrasts with Parsons' proposed definition.

Parsons' use of the perceived *adequacy* of a solution by a reasonable person is further problematic as a determining factor of what constitutes design. It asks the question, what is a reasonable person? Is an expert a reasonable person, or could a non-expert be considered a reasonable person? Galle (2016) additionally finds Parsons' use of the term inadequate problematic because it introduces a time-dependent variable. Galle contends that at any given time in history, a reasonable person "might not see a particular set of plans as inadequate for a given purpose, while at another time a reasonable person (living at that other time) might see the plans as inadequate" (p. 338). The inherent value judgement and time-based nature of Parsons' definition make it problematic in seeking a concise essential definition of design.

2.6.5 Working Definition of Design

This survey of design concepts and definitions provides an overview of how conceptualisations of design have changed over time. However, it fails to point to a concise or universal definition of design. This is in part due to modern pluralist views of design and the all-encompassing nature of the contemporary design discipline (see Love (2000)).

Adding further to the difficulty in developing a concise definition of design, Garner and Evans (2012) find one of the difficulties with defining the term is that design can be both a noun and a verb. The term can be used to refer to the process of solving problems or creating artefacts, and it can also be used to refer to the outputs of the process – the various artefacts produced through the design process.

Using the work of Ralph and Wand (2009) and Parsons (2015) as guides, it is possible to examine the commonalities in the definitions presented here to help the thesis define the context of design. The researcher finds in these definitions common epistemological concepts of design which relate to:

- problem-solving,
- intended use,
- user or stakeholders,
- function,
- the role of information, and
- the meeting of stated parameters or requirements.

From this historical analysis, and based on these common characteristics of design, this thesis uses the following working definition of design as the basis for a conceptual model which can support the development of solutions that help fulfil the research aim:

> **DESIGN**
>
> ***(noun)*** a multi-criteria decision-making and problem-solving process which leads to the conscious creation of a design artefact in response to predetermined requirements and stakeholder needs, while recognising contextual and environmental constraints.
>
> **(verb, transitive)** to create a design artefact, in response to predetermined requirements while recognising contextual and environmental constraints.

2.6.6 Summary of Historical Definitions of Design and their Implications

By examining different understandings of design over the past 60 years, it is possible to understand the concept better. This helps us see how the philosophical underpinnings of design have changed over time and suggest ways to respond to the increased rate of technological change today and in the future.

What remains to be seen, is whether increased computer power and connectivity, which has led to new analytical and assessment tools, will create a shift in design concepts that return to the discipline’s positivist roots. Will these new technologies allow for understandings of design that are more scientific, rational, and objective in nature, in the vein of Simon and the *Science of the Artificial*? Will they conceptually move design to an analytical realm from one based on synthesis? Or, to a domain which more fully takes advantage of both?

The definition of design established for this thesis does not take a strict pluralist or neo-positivist view of design. The author sees both views as accommodated by this thesis's definition; however, if one takes the views discussed above by Papanek (1985), Lawson (2005), and others, that there are no optimal solutions to design problems, only that some are better, and some worse, that there is inherently no one right or wrong solution to a design problem, this suggests trade-offs are a required and inherent aspect of the design process. Furthermore, according to Codinhoto and Lo (2019), because the design process is dependent on a range of factors and competing interests that impact one another, the nature of the design process requires designers and clients to embrace compromise.

2.6.7 Multi-Criteria Decision-Making Processes

Trade-offs in the building design process include such things as balancing embodied energy versus operational energy, construction costs versus operational costs, or historic preservation versus sustainability. Over the course of a building design project, hundreds of decisions will be made that must consider a range of requirements, trade-offs, and stakeholder demands. According to (Serugga, Kagioglou, & Tzortzopolous, 2020), it is therefore necessary to use a robust decision-making process in the building design process.

To help address the complexity of managing trade-offs in complex scenarios, such as the multi-criteria decision making (MCDM) nature of the AE building design process, a range of decision-making tools and methods are often used by AE-design teams to support the design decision-making process (Arroyo, Mourgues, Flager, & Correa, 2018; Serugga et al., 2020). These methods include frameworks such as Choosing by Advantages (CBA), Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organisation Method for Enrichment (PROMETHEE), Complex Proportional Assessment (COPRAS), or Target Value Design (TVD), among others (Harputlugil, 2018; Isa et al., 2017; Moghtadernejad, Chouinard, & Mirza, 2018; Nielsen, Jensen, Larsen, & Nissen, 2016; Ogrodnik, 2019). Ogrodnik (2019) finds that MCDM methods represent effective tools for evaluating and selecting project solutions and are particularly helpful in balancing the trade-offs and often contradictory decision factors which come with evaluating sustainable design criteria.

According to van der Meer, Hartmann, van der Horst, and Dewulf (2019), the purpose of multi-criteria decision analysis (MCDA) frameworks is to help decision-makers, such as AE designers, deal with complex problems that are characterised by conflicting objectives. They are further intended to help organise and synthesise available information and compare alternative solutions. Similarly, a range of sustainability schemas has been developed to aid in the design decision-making process related to sustainability, such as Leadership in Energy and Environmental Design (LEED, US), Building Research Establishment Environmental Assessment Method (BREEAM, UK).

In a study that examined a range of MCDA frameworks to evaluate their advantages and disadvantages, Velasquez and Hester (2013) concluded that the advantages and disadvantages of given MCDM methods are context-specific. In another review of MCDM/MCDA methods when applied to the decision making challenges of AEC industries, Ogrodnik (2019) similarly finds that while such methods can serve as essential tools for aiding AE-design decisions, their applicability is context-specific. However, because AE designers must consider the preferences of multiple stakeholders, Ogrodnik suggests that AHP (developed by (Saaty, 1980)) is particularly useful in supporting AE-design processes. This view is reflected by Harputlugil (2018), who similarly finds that MCDM methods can aid designers in design decision-making processes and proposes AHP for use by AE designers due to its ability to numerically compare tangible and intangible criteria. In contrast, Arroyo et al. (2018) agrees that MCDM methods can assist AE designers, but find that CBA versus AHP is better suited to the process of the AE-design of buildings because of its use with Lean construction techniques and because it is more transparent in its comparison of alternatives than AHP.

It is beyond the scope of this research to present a detailed analysis and comparison of MCDM/MCDA methods (see Serugga et al. (2020) for a detailed analysis), nor does this thesis intend to recommend one method over the other. Instead, it seeks to recognise that when design is understood as a multi-criterion, decision making, and problem-solving process, a range of methods exists, or can be established to support AE designers in that process. However, while this thesis does not recommend one MCDM over another, it is noted that in reference to the scope of this research, CBA was developed by Jim Suhr while employed by the US Federal Government in the US Forest Service to facilitate the decision making process for design and construction projects (Mossman, 2013; Suhr, 1999). The author also notes that use of CBA has been incorporated into the decision-making process of a range of US Federal Agencies, such as the National Park Service (NPS) and US Forest Service (USFS) for use on design and construction projects, thereby placing its common use within the realm of practice associated with the scope of the research.

2.7 Project Stakeholders

In parallel to the need for support in design decision-making, offered by MCDM/MCDA, Serugga et al. (2020) suggest that stakeholder collaboration with designers is equally important as structured decision-making processes. They further propose that just as there should be a robust, structured system to support design decision-making, there should similarly be a system to support stakeholder collaboration. Within the context of this thesis, facility managers are seen as one of many possible stakeholders which can be involved in the design process. And while the author has chosen to focus on the stakeholder involvement of facility managers, this does not suggest FMs are more important than other potential stakeholders, only that there is an opportunity to increase their participation in the AE-design process in support of design decision-making processes.

T. W. Kim, Cha, and Kim (2016) recognise the benefit of stakeholder involvement in AE-design but suggest that architects interpret stakeholder involvement at their convenience. The authors identify seven methods for encouraging user involvement in the design process: 1) architectural programming, 2) quality function deployment, 3) post-occupancy evaluation, 4) ergonomic design, 5) evidence base design, 6) workplace planning, and 7) user stimulation. However, despite identifying these methods for increasing stakeholder involvement, in their research, they find that few methods directly involve stakeholders in AEC projects. Furthermore, while the authors identify facility managers as one group of many stakeholders, they do not discuss or identify which, if any, of their recognised methods can facilitate FM involvement in AE-design processes.

Caixeta, Tzortzopoulos, and Fabricio (2019) perform a state-of-the-art review of the literature on user and stakeholder involvement in AE-design processes and find three levels of stakeholder involvement 1) informative involvement, 2) consultive involvement, and 3) participatory design and co-design. While the authors do not identify FMs as possible stakeholders, FM involvement in the design process is seen as viable in each of the three levels; however, the first two seem particularly applicable to the benefits of FM involvement identified in Chapter 1 and proposals identified in Section 2.4, wherein FM acts as both informative stakeholders who provide information about requirements and preferences, and consultative stakeholders who respond to defined design options.

Research into stakeholder involvement in design also suggests it is the social interactions between stakeholders and designers that act as the means for creating and/or integrating group knowledge (Kleinsmann & Valkenburg, 2008). Because building design develops as decisions unfold, Zerjav, Hartmann, and Achammer (2013), Luck (2012), and Oak (2012) emphasise that the social interactions between stakeholders are necessary to enable a design to move forward. However, according to Çıdık and Boyd (2020), this does not suggest that design happens best in an unstructured, fluid environment; rather design requires enabling structures that create a basis for, and allowance of, such situated interactions to take place between stakeholders. To facilitate such interactions, they conceptually redefine design coordination as "continuously re-establishing and maintaining a 'shared sense of purposefulness'" to facilitate stakeholder involvement in design (Çıdık & Boyd, 2020, p. 18).

2.8 Bounded Rationality and Knowledge Databases

The bounded rationality of human nature suggests complex, multi-criteria problems, such as design problems, can only be addressed through collaborative efforts and knowledge sharing. Simon (1996) tells us that a decision maker's ability to make rational choices is affected by cognitive limitations, limitations in available information, time limitations, and computational capacity. As a result, human rationality is bound, or limited, in its ability to effectively make complex decisions, and decision-makers must be content with good-enough or satisficing solutions rather than maximising or optimised solutions ("Bounded rationality," 2012).

The bounded rationality of designers leads Phelps (2012) to suggest that as specialist knowledge increases, and projects become increasingly complex, holistic solutions require collaboration to overcome the limitations of our bounded rationality. Phelps further adds that these limitations can be transcended through collaboration and the use of information to communicate with each other and coordinate efforts. Through the use of shared knowledge, information, and collaboration to help overcome the bounded rationality of designers, both Liu and Issa (2016) and Jensen et al. (2019) propose that shared databases can be used to store and share general design knowledge, previously tested solutions, and lessons learned for reuse across multiple and future projects.

Taking a contrarian view to researchers such as Liu and Issa (2016) and Jensen et al. (2019), Rasmussen (2020) suggests that the assumption that the transfer of operational knowledge from operations to design to be beneficial, and would result in better design decisions, is based on a problematic premise. She notes that this is because the rationality of building designers and projects managers is bounded (Simon, 1996). Designers and project managers therefore have a limited capacity to consider all interests and knowledge when making design decisions, even when that knowledge is present (Winch, 2010, as cited in Rasmussen, 2020). According to Rasmussen (2020), this challenges the assumption that more knowledge is inherently better and suggests that because of the bonded rationality of designers, how designers handle additional knowledge is as important as how it is managed and transferred.

2.8.1 Knowledge Management

According to Gold, Malhotra, and Segars (2001), knowledge management (KM) relates to the process of creating, transferring, storing, and reusing knowledge. Jennex (2015) describes KM as the capture of knowledge that is either created or used in an organisation with the purpose of making it available for those who need it to make decisions. It achieves this goal by improving connections between the sources of knowledge in an organisation and the users of the knowledge.

The field of knowledge management is based on the premise that while valuable, the utilisation of organisational knowledge is a difficult task. Alvesson and Kärreman (2001) suggest the rise of knowledge management can be attributed to the advent of communication technologies that allow access to networks in real-time interactions, regardless of distance. According to McDermott (1999), the goal of knowledge management is connecting people so they can think together.

Shen et al. (2010) state that due to the complexity of the AECO industry, with multiple teams and stakeholders engaged over a project's lifecycle, effective collaboration is difficult to achieve without proper knowledge management and systems integration. Dave and Koskela (2009) similarly find that knowledge management is difficult in AEC industries due to the involvement of various interdisciplinary teams. H. Wang and Meng (2021) find that various KM techniques have been applied to construction projects, such as web-based applications or ontologies, but that these techniques present weaknesses in facilitating KM within AEC industries. For example, Lin (2014) and Ergen et al. (2021) found in their research that most AEC KM was stored and shared using text-based means outside the confines of project models. As a result, Ho, Tserng, and Jan (2013) and H. Wang and Meng (2021) conclude it is difficult for AEC knowledge to be shared and made understandable to all project teams. Atsrim et al. (2015) further suggest there is a need to manage information in the design process differently than in other industries. Accordingly, Jensen et al. (2019) suggest knowledge codification is a critical aspect of the AE knowledge management process. Through a knowledge codification and refinement process, knowledge can be extracted, filtered, cleaned, and reformed to be stored in knowledge repositories, such as a knowledge database (Davenport, De Long, & Beers, 1998). Knowledge management is therefore seen as an essential aspect of effective collaboration within the AE-design process.

2.8.2 Classification of Knowledge

According to Ammar-Khodja and Bernard (2008), if knowledge is to be represented and communicated, it is necessary to classify and structure it. Chandra and Loosemore (2011) suggest design knowledge can be classified as Formal vs Tacit, Product vs Process, and Compiled vs Dynamic (Table 2.14).

Table 2.14: Classifications of knowledge

Classification of Knowledge (adapted from Chandrasegaran et al., 2013)
Formal vs Tacit Knowledge
Formal Knowledge is embedded in product documents, repositories, product function and structure descriptions, problem solving routines, technical and management systems, computer algorithms, expert knowledge systems, et cetera (Owen & Horváth, 2002).
Tacit Knowledge is tied to experiences, intuition, unarticulated models or implicit rules of thumb. Tacit knowledge is necessary to create new value in a design product. It exists as the intellectual property of designers or a design team. It is generally gained over a long period of time through learning and experience, is difficult to express, and can only be transferred by the willingness of people to share their experiences. Tacit knowledge is lost with the loss of the person or team from the organisation.
Product vs Process Knowledge
Product Knowledge includes information and knowledge associated with the evolution of a design throughout its lifecycle. This includes requirements, relationships between parts and assemblies, geometry, functions, behaviour, constraints, and design rationale.
Process Knowledge can be classified as design process knowledge, manufacturing process knowledge, and business process knowledge. Process knowledge can be encoded as methods in representation and provides mechanisms for realizing design details across the lifecycle.
Compiled (Codified) vs Dynamic Knowledge
Compiled/Codified Knowledge is essentially gained from experience that can be compiled into rules, plans or scripts, cases of previously solved problems, etc. In compiled knowledge the solutions are explicit.
Dynamic Knowledge can be classified into qualitative knowledge and quantitative knowledge. At the qualitative level, knowledge may consist of: common sense reasoning, approximate theories, causal models of processes, general problem-solving knowledge, et cetera (Sriram, 2012).

Jensen et al. (2019) suggest explicit knowledge can be easily codified and communicated. Once the knowledge is codified, it can be reused. Examples of explicit knowledge which has been codified include templates, reports, checklists, or design standards. In comparison, tacit knowledge is inherently personal and is non-articulated. This makes tacit knowledge challenging to share or transfer (Vianello & Ahmed, 2009).

2.8.3 Knowledge Transfer

While technology has a crucial role in the classification, storage, and sharing of knowledge, technology does not transfer knowledge independently. Instead, knowledge transfer relies on participants or the users of a knowledge management system. According to Ahmed-Kristensen and Vianello (2015, p. 61), the success of a knowledge management strategy is therefore not dependent on the amount of information stored in repositories but in "how the information is reused in order to achieve a predefined aim …" Successful knowledge transfer is thus dependent on the collaborative behaviour of individuals.

Jensen (2012) describes knowledge transfer mechanisms as either based on personalisation or codification strategies (see also Ahmed-Kristensen & Vianello, 2015; Anh Thi Lê & Brønn, 2007). Within these mechanisms for knowledge transfer, Jensen suggests that personalisation strategies rely on informal communication between individuals and can include collaboration activities. Through these interactions, new knowledge can be generated, and tacit knowledge shared. In contrast, codification strategies depend on transferring explicit knowledge stored within knowledge repositories, such as databases.

2.8.4 Knowledge Transfer and Design Decision-Making

According to Dean and Sharfman (1996), access to appropriate knowledge profoundly impacts professional decision making. Conteh and Forgionne (2006) tell us that for knowledge to effectively aid decision making, it must be provided on time at each step or phase of a decision-making process. They further suggest expert knowledge is not as valuable as general knowledge, which is focused and pertinent to a specific decision task. Just-in-time knowledge management (JITKM) helps ensure that knowledge related to a decision-making process is available when needed. As a result, JITKM can improve and streamline decision-making processes (Conteh & Forgionne, 2005).

As noted above, Jensen et al. (2019) describe knowledge transfer between FM and design in terms of knowledge pushes, and knowledge pulls. In a knowledge pull, the receiver requests the knowledge, whereas in a knowledge push, the sender provides the knowledge, with or without a particular request or demand for it. Ahmed, Tezel, Aziz, and Sibley (2017) describe an additional knowledge transfer mechanism, which they describe as "fixed." In these fixed knowledge transfer mechanisms, knowledge is either pulled or pushed at fixed points in a project lifecycle or occurs through planned activities, such as regularly scheduled meetings. In this manner, both senders and receivers play active roles. In the context of FM involvement in AE-design, Jensen (2009) suggests the effectiveness of these knowledge transfer mechanisms depend on how motivated FMs are to share knowledge, and how willing or eager AE designers are to receive it.

Kalantari et al. (2017) suggest that effectively sharing information between AE and FM will make it possible to store requested and supplied information in one place, streamlining interactions so that information is not requested or shared multiple times. Furthermore, more effective knowledge management tools would allow designers and FMs to track their interactions over time, making it possible to corroborate their interactions with the results of design decisions and to learn from past projects. This makes it possible to evaluate design decisions and gain new knowledge for sharing in future projects (Shen et al., 2010).

2.9 Knowledge Representation

Chandra and Loosemore (2011, p. 204) suggest that because knowledge can be understood as information in context, the form in which knowledge is communicated and accessed is dependent on the content and context of the information. In a design setting, context can depend on several variables, such as the artefact being designed, the organisational context of the design process, the design philosophy followed, the design phase in which the knowledge is used, or the mind of the designer. Sunnersjö (2010) further contextualises knowledge in a design context and describes it as understanding the content, origins, and applicability of given information. According to Sunnersjö, design knowledge includes the rules that designers should adhere to and includes the background knowledge that makes design rules reviewable and understandable. Design knowledge is that which makes possible the analysis of design decisions, best practices, and rules of thumb.

In considering the role of knowledge in the design process, it is therefore necessary to consider how information is captured and how and when it will be used. According to Chandra and Loosemore (2011), there are two critical challenges associated with the capture and representation of knowledge and information in a design process:

1. Encoding design artefact and process knowledge at different design stages in a way that will lead to better quality.
2. The capture, use, and communication of knowledge between different individuals, teams, and organisations.

Regarding these two challenges, Chandra and Loosemore suggest that the first challenge is more applicable when considering sequential processes and that the second challenge is more relevant in concurrent processes. Because AE-design includes both kinds of processes, both views must be considered when seeking to inform AE-design decision-making processes by sharing FM knowledge with AE designers.

2.9.1 Design Process View of Knowledge and Integrated Knowledge Systems

Design process knowledge relates to knowledge generated and used at various stages in the design process. Speaking in the context of product design, Chandrasegaran et al. (2013) delineate the multiple forms of design knowledge based on the design phase in which they occur. In this conceptualisation, knowledge representation in early design phases is primarily linguistic and pictorial, while knowledge generated and used in later design phases favour more abstract forms of representation. As knowledge accumulation and generation increases across these phases, it becomes challenging to reuse or apply this knowledge in earlier design phases (or across projects) without using appropriate forms of representation.

In contrast to design process knowledge, Chandrasegaran et al. (2013) describe an integrated systems view of knowledge as the knowledge generated from the interaction between those involved in the design process (such as designers, design teams, or stakeholders) over the course of a project.

Szykman, Fenves, Keirouz, and Shooter (2001) suggest that a necessary aspect of supporting and expanding the development of an integrated design knowledge system is the capture and documentation of design decision rationale. Capturing design rationale can help extract design knowledge from past designs to develop lessons learned. These lessons learned can then help establish or refine design rules for reuse in new design concepts. Oti et al. (2018) add that when documenting lessons learned, the captured information should include the associated design problem, solutions, and be easy to access.

2.10 Understanding of BIM in the Research Context

Several of the proposals identified in Section 2.4 propose the use of building information modelling (BIM) as a preferred method for knowledge management and knowledge transfer in support of FM involvement with AE-design. In noting these repeated references to BIM, and to contextualise the understanding of BIM as used in this thesis, it is briefly discussed here. Building Information Modelling has emerged as an industry standard in architecture, engineering, and construction (AEC). Because BIM creates a digital representation of design, construction, and operational processes, it facilitates the exchange and interoperability of data and information in a digital format (Eastman, 1999; Hardin, 2009). In AEC and FM industries, this allows BIM to be utilised as part of a broad set of integrated procedures and technologies that assist AECO stakeholders in planning, designing, visualising, constructing, and maintaining the built environment.

Building Information Modelling is a broad term that describes the process of creating and managing digital information about a built asset such as a building, bridge, highway, or tunnel. Adding to the breadth of the term, and creating confusion around its definition, BIM is often understood as one of three related, but independent concepts (Table 2.15).

Table 2.15: Three understandings of BIM

Three Understandings of BIM	
BIM as…	**Definitions**
Building information management	A comprehensive strategy for collecting, managing, and sharing required data / information to accurately support facility life cycle from early planning to building disposal (WBDG).
Building information model	A digital representation of physical and functional characteristics of a facility, usually consisting of a three-dimensional model integrated with a database about materials, products, components, systems, and their properties and performance (Gelder, Tebbit, Wiggett, & Mordue, 2013).
Building information modelling	The use of geometric and data modelling software to create a virtual representation and analysis of the physical and functional characteristics of a building (e.g., building performance modelling, energy analysis, daylighting analysis, structural analysis, cost estimating). (Summary by author)
In the context of FM/O, Asset Information Models (AIM) are also regularly referred to.	
Asset information model	An information model that contains structured and unstructured data relating to the operational phases of a facility and supports the strategic and day-to-day asset management processes. It can also provide information at the start of the project delivery process (ISO, 2018b).

Simpson (2013, p. 6) recognises these disparate conceptualisations of BIM and suggests that regardless of the specific definition, several necessary points define the essence of BIM.

- **Building** represents the verb *to build* rather than the noun *a building*. It is therefore relevant to any asset of the built environment.
- **Information** (or more specifically the sharing of structured information) is the fundamental concept of BIM. This includes both geometric and non-geometric information such as time, cost, fire-rating etc.
- **Model** refers to the representation of a system or process rather than exclusively a 3-dimensional representation of a person or thing. Though there can be no doubt that geometric representation is important, one must be able to simulate the various facets of the design of an asset (structural, architectural, building services etc), the construction of the asset, and the operation of the asset.

Due to the broad nature of BIM, debates over its definition have been widely discussed by other authors; however, as the scope of this research is in the US, the author adopts the definition of BIM as delineated by the United States National Building Information Model Standard (NBIMS) and the United States General Services Administration (GSA) (Table 2.16).

Table 2.16: Working definition of BIM

Working Definition of BIM
United States National Building Information Model Standard (NBIMS)
A Building Information Model (Model) is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward (WBDG, 2021).
United States General Services Administration (GSA)
Building Information Modelling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalised (modernised) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analysed to generate feedback and improvement of the facility design (GSA, 2007).

Independent of the various definitions of BIM, Smith (2009) suggests the distinguishing feature that separates BIM from previous design technologies is not its three-dimensional modelling capabilities, but its ability to structure information in an organised, defined, and exchangeable manner. The structuring of information, in relation to geometric modelling, is key in the context of this thesis. Therefore, in this thesis, discussions of BIM should be seen as a reference to the methodology or process BIM creates. This process is defined by Krygiel (2008) as:

> …the creation and use of coordinated, consistent, computable information about a building project in design – […] used for design decision-making, production of high-quality documents, prediction of building performance, and construction planning. (p. 27)

And further described by May and Williams (2017):

> …a process involving the generation and management of digital representations of physical and functional characteristics of places. Building information models (BIMs) are files […] which can be extracted, exchanged, or networked to support decision-making regarding a building or other built asset. (p. 571)

In this context, BIM is seen as a potential factor in improving and supporting design decisions and for sharing FM knowledge with AE-design. This is because at its core, BIM is a database in which "the structures of a building and their individual elements are stored. In this structure, complete geometry and the relations between the elements are recorded" (May & Williams, 2017, p. 63). This structuring of data facilitates a range of capabilities which include quantity take-offs, cost-estimating, space planning, asset management, energy analysis, and so forth (P. M. Teicholz, 2013, p. 18). Smith (2009, p. 27) suggests the database nature of BIM provides the potential for improving communication among AECO stakeholders, and, more importantly in the context of this thesis, for "*improving the quality of information available for decision making*." Eastman (2011) reaffirms this view in his finding that when adopted well, the use of BIM from the earliest design phases results in more integrated design, and leads to better quality buildings, at a lower cost, and at a reduced project duration. Lee, Oh, Kim, and Choi (2015) similarly find that BIM represents a useful tool for improving design quality by reducing design-related errors.

BIM's ability to serve as a database of building information within a common data environment provides opportunities to facilitate improved flows of information and knowledge sharing across a project's design, construction, and operational lifespan, which in turn has the potential to deliver increased value across a building's full lifecycle. A range of authors have proposed the use of BIM to increase information and knowledge sharing between AECO disciplinces (such as Ho et al., 2013; Lin, 2014; Oti et al., 2018; H. Wang &

Meng, 2021). However, Mirarchi et al. (2018) take a skeptical and contrasting view, noting that even if BIM's representation of data can provide useful information, that alone cannot be seen as knowledge sharing. Which, according to Kamaruzzaman et al. (2018), requires human decision and action.

Despite BIM's potential to improve AEC/FM knowledge sharing, multiple studies, as noted in Section 2.4, have identified obstacles which continue to limit the transfer of knowledge between built environment design and management teams. This is reflected in the view of Codinhoto (2019) who describes as one of the "mirages" of BIM the view that the use of BIM alone will somehow enhance communication and decision making. Codinhoto (2019, p. 57) further proposes that "without changes in workflows and overall culture, BIM is likely to underperform."

The basic structure of BIM further reduces its ability to facilitate knowledge sharing between FM and AE-design. By its nature, BIM focuses thought on objects through the creation and use of digital object-oriented models (Coates et al., 2010). Furthermore, because BIM primarily records and structures data in relation to model objects, and because data is not knowledge, on its own, BIM does not lend itself to the documentation and sharing of knowledge related to processes and activities. BIM should therefore not be seen as a panacea to enhancing information sharing between FM and AE; however, its potential to facilitate such interactions warrants further examination within the scope of this research.

2.11 Chapter Summary

This chapter reviews the literature findings related to barriers to and proposals for facilitating FM – AE-design knowledge sharing. It summarises and categorises these barriers and proposals as social, hybrid, or technical. The chapter also reviews literature associated with *design* as a field of inquiry and historical attempts to develop and define universal understandings of *design*. It further discusses the design process in relation to multi-criteria decision-making processes and knowledge management. In the end, the chapter discusses the understanding of BIM as used in this thesis.

3. RESEARCH METHODOLOGY

3.1 Chapter Introduction

This chapter presents and justifies the selected research methodology used in this thesis. In doing so, the chapter presents the philosophical underpinnings of the research and associated data collection and analysis techniques used. The relevance and appropriateness of the research methods used are presented.

Before attempts were made to address the study's research aim and objectives, it was necessary to establish an appropriate research methodology. Forsyth and Crewe (2006) suggest that research "involves carefully and diligently collecting information to answer a larger question" (p. 163). Hack (1984) tells us that research involves "structured forms of inquiry devoted to recurring questions, the results of which can and should be communicated to others" (p. 128). According to Groat and Wang (2013), one of the earliest commonly accepted definitions of research in architectural design, or building design contexts, was proposed by Snyder (1984, p. 2), who describes research as a "systematic inquiry directed toward the creation of knowledge." Additionally, Collis, Hussey, and Hussey (2003) states that research must analyse, explain, and create new knowledge. Furthermore, in a lay definition, the Oxford dictionary (Stevenson, 2010) defines research as: "The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions." Inherent in each of these definitions are two key elements: first, an inquiry that is systematic, and second, that an act of inquiry leads to the creation of new knowledge.

In the context of this chapter, the concept of systematic inquiry is the focus of attention. The phrase, systematic inquiry, suggests a conscious determination of how information is gathered, categorised, analysed, and presented (Groat & Wang, 2013). Research, as a form of systematic inquiry, must inherently be based on a specific methodology. Therefore, an inherent aspect of a research study is the selection of an appropriate research methodology.

3.1.1 Research Methodology vs Research Method

Prior to expanding on the research methodology used in this study, it is helpful to differentiate between the terms research methodology and research method as used in this thesis. According to Adams, Khan, Raeside, and White (2007), a research method describes a method of conducting and implementing research. In contrast, a research methodology refers to the scientific and philosophical underpinnings behind all research. Kaplan (2017) describes research methodology as the study of the research process rather than a product of inquiry. In this context, methodology refers to broad aspects of the research process that are common to a range of disciplines and research activities.

In contrast, a research method refers to a specific range of techniques used within a broader systematic inquiry, that is to say, within a methodology. While not a universal distinction, according to Groat and Wang (2013), this represents a common understanding of the terms. Therefore, in the context of this thesis, research methodology refers to the overall approach to research undertaken for this study – the overall research plan – whereas the research method refers to a narrower, more detailed use of specific techniques or procedures used to obtain and analyse research data (Saunders, Lewis, & Thornhill, 2015). The study's research methodology is the subject of the whole chapter, and the research method (or methodological choice) is represented by an individual section within the broader chapter (Section 3.2.3).

3.1.2 Built Environment Research Context

Aken (2004) describes conventional research as being descriptive in nature and linked to explanatory sciences such as physics and sociology. He argues that, on the other hand, research in management fields should rely on a partnership that is both description-driven and prescription-driven (Table 3.1). He further describes prescription-driven research as research that develops research products that can be used to design solutions for management problems.

Kehily and Underwood (2015) reflect a similar view in discussing built environment research and note that built environment researchers are often not purely concerned with an interpretive research methodology which seeks to describe an existing phenomenon; instead, they often seek to create new knowledge, work processes, or technologies that require the use of an appropriate research methodology.

Chynoweth (2009) finds additional links between built environment research and management research and notes that the built environment field has seen a dominance in management discipline research resulting in the development of a strong interdisciplinary relationship between management and built environment research. While Griffiths (2004) describes the domain of built environment knowledge and research as "a range of practice-oriented subjects concerned with the design, development and management of buildings, spaces and places."

Table 3.1: Descriptive vs prescriptive research

Distinctions between Research Focused on Description and Prescription		
Characteristic	**Research programs focused on description**	**Research programs focused on prescription**
Dominant Paradigm	Explanatory science	Design science
Focus	Problem focused	Solutions focused
Perspective	Observation	Participatory
Typical Research Question	Explanation	Alternative solutions for a given class of problem
Typical Research Product	Causal model; quantitative law	Tested by and grounded in technological rules
Nature of Research Product	Algorithm	Heuristic
Justification	Proof	Saturated evidence
Type of Resulting Theory	Organisation Theory	Management theory
(adapted from Aken, 2004, p. 236)		

Both the nature of the domain being studied, the built environment, and the nature of the research aim suggests the need for a research methodology that allows for the development of prescriptive knowledge. Johannesson and Perjons (2014, p. 24) define prescriptive knowledge as knowledge that "consists of prescriptive models and methods that help solve practical problems." They further describe prescriptive models as "blueprints for developing artefacts, while methods are guidelines and procedures that help people to work in systematic ways when solving problems."

3.2 Research Methodology Selection – Saunders Research Onion

A research methodology helps us describe the different ways in which knowledge can be created, and when appropriate, critically analyse the creation of new knowledge. It asks the question, "how should we study the world?" (Patton, 2009). It is therefore important to broadly understand research methodology before selecting an appropriate methodology. To aid in the selection of an appropriate research methodology for this study, the "Research Onion" described by Saunders et al. (2015) (Figure 3.1) was followed as a guide.

Whereas the Research Onion is used to describe the research methodology, it is important to recognise other approaches could have been selected. In addition to the Saunders et al. Research Onion, other approaches were considered, such as those described by Creswell and Creswell (2018); Crotty (1998); Kaplan (2017). From these approaches, the Research Onion was selected due to its ability to provide for a broader range of considerations.

Furthermore, in the author's view, the Research Onion provided a more precise model for determining the most logical methodology to adopt. This was in part due to the differences between built environment research and research undertaken in the more traditional physical sciences (scientific method) and traditional social sciences. The Research Onion model was developed for research undertaken by business students, and as this study related to the business of design, construction, and facility operations, this further reiterated the appropriateness of the model.

The Saunders et al. (2015) model is divided into six nested layers (similar to an onion) that increase in detail as one moves from the outside: 1) Philosophy, 2) Approach to Theory Development, 3) Methodological Choice, 4) Strategy(ies), 5) Time Horizons, and 6) Techniques and Procedures. The individual choices made within this thesis concerning each layer of the research onion are highlighted in red in the figure below (Figure 3.1, adapted from Saunders et al. (2015)).

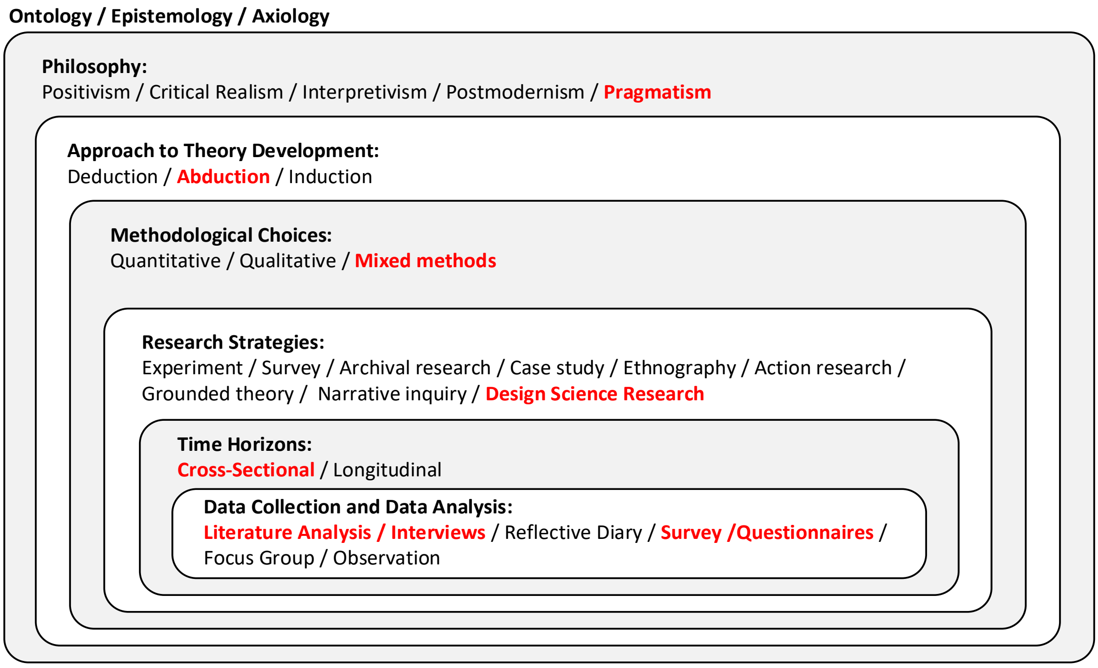


Figure 3.1: Saunders et al. Research Onion

3.2.1 Philosophy

The outermost layer of the research onion is identified as Philosophy. According to Creswell and Clark (2011), research philosophies provide a foundation for conducting research. Saunders et al. (2015) describe a research philosophy as the system or beliefs and assumptions held by the researcher about the development of knowledge. In any research project, a series of assumptions are made by the researcher. These assumptions may be epistemological assumptions (regarding the nature of human knowledge), ontological assumptions (regarding the nature of reality), or axiological assumptions (regarding a researcher's values). These assumptions ultimately shape how the research question is understood, the methods used, and how the findings are interpreted (Crotty, 1998). Because a research philosophy represents a belief about how data related to a phenomenon should be gathered, analysed, and used, it is vital for researchers to be aware of the assumptions they make in gaining knowledge during a research study.

Ontology:

Ontology refers to assumptions made by the research about the nature of reality and the world at large (Tashakkori & Teddlie, 2003). It asks, "what do we believe about the nature of reality?" (Patton, 2009) An ontological stance taken by a researcher addresses the assumptions through which they perceive the broader questions of how the world operates (Saunders et al., 2015). Ontological debates are concerned with the possibility of a single verifiable reality or truth vs inevitability of multiple, socially constructed realities (Patton, 2009). Ontology asks the researcher to be aware of and to question the nature of reality, to examine the difference between reality and how one perceives it. As an example, a positivist approach to ontology views social entities as existing externally and independently of the social actors concerned with their existence. In contrast, subjectivism holds that social phenomena are created by the actions or perceptions of those same social actors (Saunders et al., 2015).

Epistemology:

Epistemology refers to assumptions made about the nature of knowledge, what constitutes knowledge in a particular field of inquiry, and how that knowledge is communicated.

Epistemology may also refer to the relationship between the knower and to the known (Tashakkori & Teddlie, 2003). Epistemology asks, "how do we know what we know?" Epistemological debates raise questions about the possibility and desirability of objectivity, subjectivity, validity, generalisability, et cetera (Patton, 2009).

Epistemology seeks to find knowledge and then addresses facts according to that knowledge. Epistemological approaches are often associated with scientific research as it helps in finding information that is verifiable or testable (AllAssignmentHelpUK, 2017).

Axiology:

Axiology refers to the role of values within the research process (Tashakkori & Teddlie, 2003). Axiology asks a researcher to consider how their values and opinions impact the collection and analysis of data. According to Heron (1996), our values are the guiding force behind all human action and researchers demonstrate axiological skill when they can articulate the values underlying their judgements about what to research and why, and how to go about doing it. By choosing a particular topic over another, a researcher expresses their values by suggesting one topic is more important than another. Furthermore, selection of a research philosophy or data collection procedure also represents a reflection of a researcher's values. For example, conducting a survey based on data collected through interviews suggests personal interactions are more valued than views expressed anonymously through online questionnaires (Saunders et al., 2015).

3.2.1.1 Research Philosophies

Saunders et al. identifies five major research philosophies: positivism, critical realism, interpretivism, postmodernism, and pragmatism.

Positivism:

Positivism focuses on a scientific, empiricist method which seeks to develop data and facts uninfluenced by human interpretation or bias. It represents the philosophical stance of natural scientists working with observable realities who seek to produce law-like generalisations (Saunders et al., 2015). It is often based on quantitative research (Remenyi, 1998). Positivists seek universal rules and laws to explain or predict behaviour and typically rely on a highly structured research methodology in order to facilitate replication (Gill & Johnson, 2002).

Critical Realism:

Critical realism seeks to explain what we see and experience in terms of the underlying structures that shape observable events (Saunders et al., 2015). Critical realists view reality as external and independent of the observer; however, this reality is not necessarily accessible through our observation or knowledge of it. According to critical realism, we experience sensations which are manifestations of things in the real world, rather than experiencing the actual things themselves. This philosophy often seeks to understand the bigger picture of which we may only see a small part. For example, if one is trying to understand a specific phenomenon, one may look at the social structures which gave rise to that phenomenon first. Critical realist research, therefore, looks to provide explanations for observable events by looking for the underlying causes and mechanisms (Saunders et al., 2015). Critical realists often perform historical analysis of social or organisational structures and examine how they have changed over time (Reed, 2005).

Interpretivism:

Interpretivism was developed as a critique of Positivism from a subjectivist perspective. Interpretivism recognises that humans are different from physical events or phenomena because we create meaning. It is this meaning that interpretivism seeks to study and understand. Because different people with different backgrounds, experiences, cultures, et cetera, interpret events differently and create their own meanings, interpretivists are critical of positivist attempts to discover universal laws. Instead, they seek to create new interpretations of social worlds and context. Interpretivist research seeks to create meaning from a specific set of circumstances and interactions related to specific individuals at a specific moment in time. With its focus on meaning-making, interpretivism is explicitly subjectivist. According to Saunders et al. (2015, p. 141), this presents an axiological implication in that "interpretivists recognise that their interpretation of research materials and data, and thus their values and beliefs, play an important role in the research process."

Postmodernism:

Postmodernism focuses on the role of language and power relations. It seeks to question accepted ways of thinking and to give a voice to alternative or marginalised views. Postmodernists reject an objectivist or realist classification of things, and instead, emphasise the “chaotic primacy of flux, movement, fluidity and change” (Saunders et al., 2015, p. 241). According to Saunders et al., postmodernist researchers seek to question and expose the power structure and relationships found in dominant realities. This typically takes the form of deconstructing or taking apart such realities to search for instabilities within widely accepted truths. Like interpretivists, postmodernists undertake in-depth investigations of phenomenon.

Pragmatism:

Pragmatism recognises there are multiple ways of interpreting and viewing the world, and in fact, there may be multiple realities. Furthermore, there are different ways of undertaking research, and a single point of view can never give the entire picture. Pragmatists view research as beginning with a problem. They then seek to discover practical solutions to the identified problem that inform future practice. Such research is interested in practical outcomes rather than abstract distinctions. Within a pragmatist philosophy, the most crucial aspect of determining an appropriate research design and strategy is the research problem being addressed and the associated research aim. Accordingly, a pragmatist approach emphasises practical outcomes to the associated research question or aim. According to Saunders et al. (2015), if a research problem does not suggest one particular research approach should be adopted, in the pragmatist’s view it is entirely possible to work with different types of knowledge and methods” (143). However, this does not suggest pragmatists exclusively use a mixed method approach to research. Rather, they use the most appropriate methods that facilitate the collection of well-founded, reliable, and relevant data that advances the research (Kelemen, 2008).

3.2.1.2 Research Philosophy – Selection and Summary

Before selecting an appropriate research philosophy, it was necessary to define the epistemological worldview and associated ontological and axiological assumptions held by the researcher. These assumptions formed the basis for selecting an appropriate research philosophy as all recognised methodologies “have their role to play within the context of the assumptions on which they have been developed” (Morgan & Smircich, 1980, p. 498).

This research study’s ontological, epistemological, and axiological assumptions were identified as follows:

Ontological Assumption:

Reality exists and can be studied and understood. In the context of this research, design exists as a phenomenon that can be studied. Design is a problem-solving endeavour which relies on access to meaningful information to be effective. Improve access to quality information, and design as a problem-solving endeavour will improve. Accordingly, design can be studied, improved, analysed, and validated. Good vs poor design can be determined.

Epistemological Assumption:

There are different types of knowledge – ranging from textural data or visual data to numerical data, from facts to opinions, from narratives to stories – that can be considered legitimate. In the context of this thesis, design is an intentional activity engaged in by designers. Goals are inherent to designers and designers must have intentionality. To gain legitimate knowledge about design, it is best to engage with those involved in the process.

Axiological Assumption:

Improving the design process and related built environment is a worthwhile endeavour. Designers and facility managers have meaningful contributions to make in the design process and warrant investigating their opinions. The opinions of designers and facility managers have value in studying the design process.

Based on these ontological, epistemological, and axiological assumptions, and the stated research aim, a pragmatist research philosophy was selected as a guide for the work.

Given the nature of the phenomenon investigated, the research project collected qualitative and quantitative data. This dual nature of data collection suggested the adoption of a pragmatist research philosophy. Pragmatism allowed the use of a mixed methods approach while avoiding the duelling nature of other philosophies (for example, interpretivism vs positivism). Because pragmatism lies in the middle of positivist and interpretivist research philosophies, it freed the researcher to focus on identifying solutions to the associated research aim. Furthermore, because this research aim sought to discover a practical solution to an identified problem, a pragmatist philosophy was justified.

3.2.2 Approach to Theory Development

According to Saunders et al. (2015), all research involves the use of theory. Moreover, while the theory underlying a research project may not be made explicit in the design of the research, it is typically made explicit in the conclusions and presentation of findings. In this context, the use of the term theory attempts to explain the nature of the relationship between variables or concepts. It answers the questions of what, how, why, and who. For any given research study, the project may be designed to test a theory, develop a new theory, or pursue some combination of the two (Saunders et al., 2015).

Answering the question of whether establishing a theory is the first step of the research process or emerges from steps taken during the research process itself, is an essential step in establishing a research methodology. The question of when theory is developed is addressed through three contrasting approaches to theory development: deductive, inductive, and abductive.

Deduction:

Deductive reasoning occurs when a conclusion is derived logically from a set of premises – a conclusion is correct when all the associated premises are true (Ketokivi & Mantere, 2010). Deduction relates to what is often thought of as scientific research that involves the development of a theory that is subjected to a series of rigorous tests. If a research study starts with a theory, which may be developed through a literature review, and a research strategy is subsequently designed to test this theory, a deductive approach is being used (Saunders et al., 2015). A deductive approach is often thought of as a *top-down* approach, or as going from general to specific. A deductive approach is typically well suited for a positivist philosophical approach (Collins, 2019).

Induction:

Inductive reasoning is used when there is a gap in an argument between the premises observed and the conclusion(s) made from those premises. In inductive reasoning, a conclusion is seen as being supported by observations made (Ketokivi & Mantere, 2010). Induction relates to what is often thought of as social science research. When research starts by collecting data to explore phenomena, and a theory is generated or built from this research, such as the development of a conceptual framework, an inductive approach is being utilised (Saunders et al., 2015).

In an inductive approach, observations made during the act of research lead to the development of a theory. Observations are generally studied within the context of the phenomenon, and it is often referred to as a *bottom-up approach*, or as going from the specific to the general. Because an inductive approach is based on a specific set of circumstances and social actors, it is not always possible to make generalisations through inductive theory development. Therefore, an inductive approach is typically well suited for an interpretivist philosophical approach (Collins, 2019).

Abduction:

Abductive reasoning presents a third approach to theory development. Abductive reasoning begins when a surprising fact is observed that leads to a conclusion rather than a premise (Ketokivi & Mantere, 2010). Working from this conclusion, possible premises are determined that are sufficient to support the conclusion. It is presumed that if the premises are true, the conclusion would subsequently be true. In such a context, because it has been determined that these premises are sufficient (or nearly sufficient) to generate a conclusion, there is sufficient reason to believe the conclusion is also true (Saunders et al., 2015). Where deduction is typically seen as moving from theory to data and induction approach is seen as moving from data to theory, an abductive approach moves back and forth, combining deduction and induction (Suddaby, 2006).

According to Saunders et al. (2015), if a researcher collects data to explore a phenomenon, to identify themes, to explain patterns, or to generate a new, or modify an existing, theory which is then tested through additional data collection, an abductive approach is used.

3.2.2.1 Approach to Theory Development – Selection and Summary

This research used both inductive and deductive approaches to develop an improved method for sharing FM/O knowledge and expertise with AE designers. A deductive approach was used to establish and validate a point of departure. While an inductive approach was used to build a theory regarding the best way to address the research aim through the development of a conceptual framework. This framework was then tested, and modified, through new data collection. Due to its back-and-forth nature, an abductive approach to theory development was selected for this study. Furthermore, an abductive approach was consistent with a pragmatist research philosophy and facilitated more robust results by combining aspects of both deductive and inductive approaches.

3.2.3 Methodological Choice

Saunders et al. (2015) describe the next three layers of the Research Onion as focused on the process of research design – or the plan for how a research question or aim is turned into a research project or study.

The first of these research design-related layers is identified as methodological choice. In choosing an appropriate methodological choice, the first choice one must consider is the nature of the research being conducted and the type of data that will be collected in the process. Saunders et al. (2015) present quantitative, qualitative, and mixed methods as available options. One way of commonly differentiating quantitative research from qualitative research is by whether numeric data or non-numeric data is collected. However, according to Saunders et al., while it is essential to differentiate between the two methods, doing so is problematic and narrow. Creswell (2014) suggests a more complete way to view the differences between quantitative and qualitative research is through the underlying philosophical assumptions a researcher brings into a study, the types of research strategies used, and the methods used in conducting the research strategies.

Quantitative:

Creswell (2014, p. 4) describes quantitative research as an "approach for testing objective theories by examining the relationship among variables." These variables can successively be measured, allowing the numbered data to be analysed through statistical procedures. Through this analysis, it can be determined whether original predictive generalisations hold.

Quantitative research is often associated with a positivist research philosophy and plays an essential role in physical science research; however, Saunders et al. (2015) suggest, depending on the method for data collection, quantitative research may fit partly within an interpretivist approach, or within realist or pragmatist philosophies.

Qualitative:

Creswell (2014, p. 4) describes qualitative research as "an approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem." This process typically takes an inductive approach to theory development as a qualitative research design is often used to build theory from emergent themes (Saunders et al., 2015). However, Yin (2017) suggests some qualitative research may start with an inductive approach that tests an existing theory using qualitative procedures. Alternatively, qualitative research often fits within an abductive approach to theory development that develops inductive inferences and then iteratively tests deductive ones throughout the research (Saunders et al., 2015).

Qualitative research examines "participants' meanings and the relationships between them" through a variety of data collection and analytical procedures. Through this, it can be used to develop conceptual frameworks and theoretical contributions (Saunders et al., 2015, p. 168). In qualitative research, data collection is often non-standardised, which allows questions and procedures to emerge and be altered during the research in a natural and interactive process. This approach is likely to use a non-probability sampling method Section 3.2.6.4).

Qualitative research is often associated with an interpretivist approach to research, but may also be used within realist and pragmatist philosophical approaches (Denzin & Lincoln, 2013; Saunders et al., 2015). It is associated with interpretivism because, according to Saunders et al. (2015), researchers "…need to make sense of the subjective and socially constructed meanings expressed about the phenomenon being studied."

Mixed Method:

Mixed methods research combines both quantitative and qualitative data collection procedures and analysis techniques. This may be done either concurrently or successively (Saunders et al., 2015). Creswell (2014) suggests this combination forms the core assumption underpinning mixed methods as a mode of inquiry. He suggests that the combination of qualitative and quantitative approaches can provide a more complete understanding of a research question than neither approach would be able to alone. Critical realist and interpretivist philosophical approaches are often associated with mixed methods research. In addition, pragmatism often takes advantage of mixed methods as it views the adoption of a particular philosophical stance as limiting. Instead, pragmatism views research philosophies as a continuum and looks for a philosophical position, or a mixture of positions, that will best fulfil the research. Pragmatists view the nature of the research question and the likely research consequences as the driving forces in determining the appropriate methodological choice. Therefore, both quantitative and qualitative approaches are utilised by pragmatists with the exact choice being determined by the nature of the research at hand (Nastasi, Hitchcock, & Brown, 2010; Saunders et al., 2015; Tashakkori & Teddlie, 2003).

Table 3.2: Methodological choice key characteristics

Methodological Choice Comparison		
Quantitative	**Mixed methods**	**Qualitative**
Pre-determined	Both predetermined and emerging methods	Emerging methods
Instrument based questions	Both open- and closed- ended questions	Open-ended questions
Performance data, observational data, and census data	Multiple forms of data drawing on all possibilities	Interview data, observation data, document data, and audio-visual data
Statistical analysis	Statistical and text analysis	Text and image analysis
Statistical interpretations	Across databases interpretation	Themes, pattern interpretation
(adapted from Creswell & Creswell, 2018, p. 16)		

3.2.3.1 Methodological Choice – Selection and Summary

Due to the qualitative and quantitative nature of the investigation, a mixed method approach was adopted. This choice was consistent with a pragmatist research philosophy and an abductive approach to theory development. The use of a mixed method approach facilitated more robust results by combining qualitative and quantitative methods. Because mixed methods allowed for the collection of complementary data and the ability to conduct counterpart analysis, it enabled the researcher to collect a stronger chain of evidence than could be collected by a single method alone (Yin, 2017). For example, Saunders et al. (2015) suggest a researcher may wish to employ interviews in the exploratory stages of a research project to gain a better understanding of key issues, followed by a survey or questionnaire to collect descriptive or exploratory data, as was done in this study.

3.2.4 Research Strategy(ies)

The research strategy helps focus the research. In the context of this study, a research strategy is understood as a general plan outlining how a researcher will go about answering a research question (Saunders et al., 2015). A research strategy represents a link between the research philosophy and the subsequent choice of procedures and techniques used to collect and analyse data (Denzin & Lincoln, 2018).

According to Saunders et al. (2015), the key to choosing an appropriate research strategy, or strategies, is that a reasonable level of coherence is achieved through the research design. No research strategy should be viewed as superior, or inferior; however, the selected strategy(ies) must enable the researcher to answer the associated research question or aim and achieve the aligned research objectives. Selection of an appropriate research strategy should, therefore, be guided by the research aim and objectives. Additionally, the coherence to which these link to the research philosophy, approach, purpose, and practical concerns such as the extent of existing knowledge, the amount of time and resources available, and access to potential participants and other forms of data should also be considered.

Saunders et al. (2015) identify eight research strategies: experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory, and narrative inquiry. In the context of this study, an additional research strategy, design science research (DSR), is added and discussed below in conjunction with those identified in the Research Onion. While each of these strategies is described in isolation below, it is important to recognise that they are not mutually exclusive. For example, Saunders et al. (2015) tell us it is quite possible to use a survey strategy within a case study or to combine several strategies within a mixed methods approach.

Experiment:

According to Saunders et al. (2015), the feasibility of using an experiment is dependent on the research question. Saunders et al. further describe an experiment as a research strategy whose purpose is to study the likelihood of change in an independent variable, causing a change in a second, dependent variable. Among other things, experiments require the definition of null and alternative hypothesis, the random allocation of participants, manipulation of an independent variable, measurement of change in an independent variable, and the control of other variables. They are often used in a positivist context.

As experiments use predictive hypotheses instead of open research questions, they are generally not used in business and management research which often inquire about the relationship between variables. Therefore, experiments are better suited for testing cause and effect or probability and causality among selected variables and are typically associated with quantitative research. These characteristics made the use of an experiment-based research strategy unnecessary and unsuited for this study.

Survey:

Survey use as a research strategy typically involves the structured collection of data from a large population. While the term survey often refers to the collection of information and data through a questionnaire, as a research strategy, it includes additional techniques such as structured observations or interviews (Saunders et al., 2015). Surveys are often associated with quantitative research. Furthermore, because surveys are frequently used to answer what, who, where, how much, and how many questions, they are often used for exploratory and descriptive research. In addition, data collected from a survey strategy can be used to suggest possible relationships between variables and to produce models for those relationships.

This study required the collection of insights, opinions, and experiences from multiple persons to fulfil the aim and objectives. Therefore, a survey strategy was seen as an appropriate research strategy for this study.

Archival research:

Archival research relies on the analysis of administrative records or historical documents as principal sources of data (Saunders et al., 2015). The study of government collected data, such as census data, represents an example of archival research. Archival research may involve quantitative or qualitative research, or a mixed methods design that combines both.

As this research sought the insights, opinions, and experiences from persons involved in the AE-design and FM/O processes, versus the researcher's interpretation of historical documents, archival research was not a suitable research strategy for the study.

Case study:

Saunders et al. (2015) describe case study research as research that involves an empirical investigation of a contemporary phenomenon within a real-life context. Case study research may involve either quantitative or qualitative research, or a mixed methods design that combines both. Groat and Wang (2013) suggest that by definition case study research is conceived in terms of particular cases in particular situations. Case study research may focus on a single case, or multiple cases in a single domain or area and can provide insight into the specific nature of those cases.

While case study research has the capacity to help explain causal links, it was not seen as an appropriate research strategy for this study as there are no cases to examine and the time frame of the domain being studied (design, construction, and operations of a built facility) further made case study research impractical within the context of a single thesis. However, case study research is suggested as a means in future research for further testing the outcomes of the study and for overcoming some of its research limitations (Section 1.5).

Ethnography:

Ethnography focuses on the description and interpretation of the social world through first-hand field study (Saunders et al., 2015). Ethnographic research is typically associated with qualitative research. Groat and Wang (2013) suggest a defining characteristic of ethnographic research is the reliance of observation as a primary data collection source. Creswell and Creswell (2018) describe ethnography as coming from anthropology and social sciences where a researcher studies the behaviour and language of a cultural group in a natural setting to examine shared patterns of behaviour.

As this research did not require the study of cultural processes and meaning sharing within a social context, ethnography was not suitable for the study. Furthermore, the reliance on an author's observations, the focus on singular groups, in site-specific settings, and the length of time required for ethnographic research made it an unsuitable strategy for this study.

Action research:

As a research strategy, action research is concerned with the management of change and involves close participation between researchers and practitioners, or clients. According to Saunders et al. (2015), action research is designed to develop solutions to real organisational problems using a collaborative and participatory approach. Action research requires participation on the part of the research with members of an organisation. However, results which come from action research should also inform other contexts beyond the immediate relationship included in the study. Action research is typically associated with qualitative research.

While action research could be used as a strategy to address the aim and objectives, because the researcher was not situated within an organisation, or doing research directly with an organisation in a participatory manner, action research was not selected for this study.

Grounded theory:

Grounded theory describes a research strategy in which theory is developed through the collection of data from a series of observations or interviews. Grounded theory typically involves an inductive approach and does not start with a hypothesis to be tested. In grounded theory, theory emerges from the analysis of empirical data. Grounded theory research is typically associated with qualitative research (Johannesson & Perjons, 2014; Saunders et al., 2015).

As this research started with a deductive approach that established a point of departure and associated research aim and objectives, a grounded theory strategy did not fit the study. While some features of the conducted research reflected some characteristics of grounded theory, such as the use of thematically coded semi-structured interviews, the study did not entirely fit within the context of a grounded theory strategy.

Narrative Inquiry:

Narrative inquiry represents a qualitative research strategy that seeks to collect the experiences of participants as whole accounts or narratives (Saunders et al., 2015). According to Miller and Salkind (2002), narrative research "typically focuses on studying a single person, gathering data through the collection of stories, reporting individual experiences, and presenting the meaning of those experiences for the individual" (148). Key characteristics of narrative inquiry include an emphasis on the importance of learning from a participant in a setting. Learning occurs through the stories told by individuals, and these stories constitute the data gathered by the researchers. Narrative inquiry research is typically associated with qualitative research.

As narrative inquiry is dependent on the telling of complete stories by participants, and analysis of those complete stories by the researcher, it was not seen as appropriate for fulfilling the stated research aim and objectives.

Design Science Research:

Design Science Research (DSR) is defined by Johannesson and Perjons (2014, p. 7) as the "scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest." The starting point of a DSR strategy is the view that something is not quite right in the world and needs to be changed. Design science researchers seek to develop artefacts that are introduced to the world to make it different or better. In addition to knowledge, artefacts represent an outcome of the DSR strategy. These artefacts represent objects made by humans with the specific intention to be used to address a practical problem. Design science research is often used in information technology and information systems research, however, as a research strategy, it applies to many other areas of inquiry (Johannesson & Perjons, 2014).

van Aken (2005) describes the goal of DSR as the development of new knowledge, which professionals in the field(s) associated with the research, can use, and implement in their practices. It produces descriptive, explanatory, and predictive knowledge. This process of knowledge generation manifests itself in the design, building, and application of an artefact (Hevner, March, Park, & Ram, 2004; Markus, Majchrzak, & Gasser, 2002). Markus et al. (2002) find the production of an artefact as a part of the DSR process helps researchers better understand the problem before them.

This study sought to develop solutions that address a practical problem. In this context DSR was seen as an appropriate research strategy for this study. The use of DSR within this study is described in greater detail in Chapter 4.

3.2.4.1 Research Strategy – Selection and Summary

In reference to the Research Onion, Saunders et al. (2015) tell us the research aim, approach, philosophical underpinnings, time and resources available, access to participants and data, et cetera, must all be considered in determining an appropriate research strategy. In this study, the selected research strategies must be able to facilitate the development of practical solutions that fulfil the aim.

This thesis aimed to develop solutions that facilitated information sharing between FM/O and AE-design teams. This was both developmental and prescriptive research and required an appropriate methodology. This research, therefore, undertook a DSR strategy – which by definition intends to change the state of the world through the introduction of novel artefacts (Johannesson & Perjons, 2014) – within a mixed methods research methodology that was grounded in a Pragmatist philosophical approach.

While this study undertook a mixed methods approach that included interviews and surveys, DSR was the primary strategy. Prior to selecting DSR for this role, case study research and action research were also considered by the researcher. However, when analysed side-by-side in the context of this research study, DSR was determined to be more appropriate (Table 3.3).

Table 3.3: Comparison of DSR, case study, and action research

Comparison of DSR, Case Study, and Action Research			
Characteristics	**Design Science Research**	**Case Study**	**Action Research**
Objectives	Develop artefacts that enable satisfactory solutions to practical problems	Assist in the understanding of complex social phenomena	Solve or explain problems of a given system by generating practical and theoretical knowledge
	Design and recommend	Explore, describe, explain, and predict	Explore, describe, explain, and predict
Main Activities	Define the problem. Suggest Develop Evaluate Conclude	Define conceptual structure Plan the cases(s) Conduct the pilot Collect data Analyse the data Generate report	Plan actions Collect data Analyse data and plan action Implement action Evaluate results Monitor (continuous)
Results	Artefacts (constructs, models, methods, instantiations) and improvement of theories	Constructs Hypothesis Descriptions Explanations	Constructs Hypothesis Descriptions Explanations Actions
Type of Knowledge	How things should be	How things are or how they behave	How things are or how they behave
Researcher's Role	Builder and/or evaluator of the artefact	Observer	Multiple, due to the action research type
Empirical basis	Not mandatory	Mandatory	Mandatory
Researcher-Researched Collaboration	Not mandatory	Not mandatory	Mandatory
Implementation	Not mandatory	Not applicable	Mandatory
Evaluation of Results	Applications Simulations Experiments	Comparison against theory	Comparison against theory
Approach	Qualitative and/or quantitative	Qualitative	Qualitative
Specificity	Generalisable to a certain class of problems	Specific situation	Specific situation
Legend/Key	**Applies to thesis**	**Partially applies to thesis**	**Does not apply to thesis**
Based on Lacerda et al. (2013) as cited in (Dresch et al., 2015)			

3.2.5 Time Horizon

In a research study, it is necessary to determine the window of time to which a study applies. The time frame available, or required, to conduct a research study is referred to as the time horizon. Saunders et al. (2015) reference two different time horizons available to a research process: cross-sectional and longitudinal. Cross-sectional studies involve the study of phenomena at a given point in time and are representative of a snapshot taken at a particular point. In contrast, longitudinal studies seek to understand change and development over an extended period and are representative of a diary.

3.2.5.1 Time Horizon – Selection and Summary

The research aim represented explorative research which used current and developing technologies to create a framework. For these reasons, a cross-sectional time horizon was appropriate. A cross-sectional time horizon was also selected for this study due to the limited time available for a PhD thesis and the strict requirements for the timely collection of data and the presentation of findings. A longitudinal study was also impractical due to the length of time associated with typical design and construction projects (a single project may span many years from conceptualisation to occupancy). A longitudinal study that examined the design, construction, and operations of a single construction project from beginning to end would have taken many years and could not fit within the time limitations of a PhD thesis. Therefore, a cross-sectional approach was adopted that provided a snapshot of data from interviews, surveys, and validation interviews in relation to the development of the framework.

3.2.6 Procedures and Techniques

Data collection and analysis represent one of the most critical aspects of conducting research. In reference to data collection and data analysis, Saunders et al. (2015) identify the following essential considerations: sampling, secondary data, and primary data. Each of these considerations is discussed within the context of this study below.

3.2.6.1 Data Collection

Secondary Data

Secondary data represents data initially collected for another purpose. Secondary data can be further analysed by the same, or subsequent researchers to provide additional or different knowledge (Saunders et al., 2015). Secondary data is often referred to as existing or available data. Several types of secondary data typically exist such as personal documents, official documents, physical data, or archived research data (Tashakkori & Teddlie, 2003).

Primary Data

Primary data is data collected specifically for the associated research being undertaken. Several types of primary data collection exist, including observation, semi-structured interviews, in-depth and group interviews, and questionnaires (Saunders et al., 2015).

3.2.6.2 Data Collection Procedure – Selection and Summary

Both primary and secondary research were utilised for this study. Secondary research included a review of relevant academic literature, government reports, and industry documents. Primary research included a series of interviews, questionnaires, and validation interviews. These data collection procedures are discussed below.

Literature Review: As the research aim related to both FM/O and AE-design teams, relevant literature was reviewed from a range of design and FM/O topics. A rationale for the focus on the integration of FM/O knowledge in design was presented in the Chapter 1.

Semi-Structured Interviews: As the research aim related to information sharing between facility management and operations and AE-design teams, the views of AE-design teams and facility managers were taken into consideration. AE and FM professionals were interviewed to document their opinions regarding the sharing of FM/O knowledge between AE-design teams and FM professionals.

Online Questionnaire: An initial framework was developed based on the literature review and qualitative data obtained from interviewing AE and FM/O professionals. A follow-up questionnaire was administered to test the assumptions made in an initial framework and the conclusions taken from the semi-structured interviews and literature review.

Validation Interviews: Following the interviews and questionnaire, the initial framework was refined and further developed. Validation interviews with practicing facility managers and AE designers were used to validate and refine the framework.

3.2.6.3 Data Analysis

Research findings and associated data for this study included both quantitative and qualitative data. Findings were analysed using a range of qualitative and quantitative data analysis techniques to identify and examine meaningful and symbolic content generated by the varied research methods described above. Qualitative data underwent analysis using both deductive and inductive approaches. Deductive analysis was used to group data and identify similarities and differences while an inductive approach used thematic analysis to group appropriate data in search of meaningful relationships. Data analysis techniques selected for each data collection activity of the project is described below with a more detailed discussion provided in Chapter 4.

Semi-Structured Interviews: Data collected from semi-structured interviews was analysed using thematic analysis techniques. These results were used to validate and refine findings from the literature review.

Online Questionnaire: Data collected from survey responses was analysed with descriptive statistics for Likert items and deductive thematic analysis for open-ended questions. These results validated findings from the literature review and semi-structured interviews.

Validation Interviews: Data gathered from validation interviews was analysed using deductive thematic analysis techniques. These results, from interviews with practicing AE and FM/O professionals, were used to validate and refine the DSR artefact.

3.2.6.4 Data Sampling

Saunders et al. (2015) describe sampling as the technique for determining the subgroup or portion of a larger population that will take place in a study. This contrasts with a census approach to data sampling. A census approach is used when it is possible to collect and analyse data from every possible case or group member related to a study. Because this is typically impossible, a target population is used, representing a subset of a larger population.

According to Johannesson and Perjons (2014), sampling is a concern in any study involving surveys. Sampling, or the selection of individuals within a population to participate in a research study, is almost always required as studying an entire population is prohibitive in both cost and time. Saunders et al. (2015) identify two sampling techniques available when conducting research:

1. Probability or representative sampling
2. Non-probability or judgmental sampling

Probability Sampling

Saunders et al. (2015, p. 724) describe probability sampling as a "selection of sampling techniques in which the chance, or probability, of each case being selected from the population, is known and is not zero." In probability sampling, the chance of any unit being chosen from within a population is generally equal, and the units chosen from a population are done so with some level of randomness (Trochim, 2006). Probability sampling techniques are commonly utilised in survey-based research. This allows statistical inferences to be used in data analysis so that results may be considered as representative of a population (Saunders et al., 2015).

Non-Probability Sampling

Non-probability sampling represents a sampling technique in which the probability or chance of each case being selected is not known (Saunders et al., 2015). According to Trochim (2006), the critical difference between probability and non-probability sampling is that non-probability sampling does not involve random selection, whereas probability sampling does. Trochim further describes non-probability sampling as being either accidental or purposive. In accidental sampling, also referred to as haphazard or convenience sampling, there is no clear evidence that the sample is representative of a population. This may be seen in traditional "man on the street interviews" or other situations such as a psychology class where the sample is selected as a matter of convenience by merely asking for volunteers (Trochim, 2006).

In purposive sampling, a sample is chosen with a clear purpose in mind (Saunders et al., 2015). An example of purposive sampling would be a survey conducted on a sidewalk where the researcher only stops certain people based on predetermined criteria such as race, apparent age, gender, et cetera, as opposed to attempting to survey anyone who passes. Trochim (2006) suggests purposive sampling is likely to get the opinions of the target population but is also likely to overweigh subgroups within the population, such as those who are more easily accessible.

While proper sampling helps facilitate data gathering that might otherwise be difficult to administer, a significant challenge associated with sampling is the determination of whether the results from a sample can be generalised to the population from which it was derived. Due to this difficulty, Johannesson and Perjons (2014) suggest it is helpful to distinguish between representative samples and exploratory samples. Where a representative sample seeks to reflect a mirror image of an entire population (that the sample contains the same distribution of relevant characteristics as the entire population), an exploratory sample "is not required to be representative of its population but instead is used as a means for gathering information in order to explore a new area" (2014, p. 43). Because the population in an exploratory sample is targeted due to its ability to provide insight and new ideas, it is not essential that the targeted population faithfully mirrors the entire population from which it is drawn.

According to Saunders et al. (2015), non-probability sampling techniques can be used when a research study's aims and objectives call for an alternative form of sample selection (such as in an exploratory sample).

Purposive sampling represents a form of non-probability sampling, which is useful for generating an exploratory sample (Johannesson & Perjons, 2014; Saunders et al., 2015; Tongco, 2007). Furthermore, purposive sampling may be used when the population is selected with a specific purpose in mind, such as when the main focus of data collection is to gain an in-depth understanding of an issue (Saunders et al., 2015). Purposive sampling has been similarly described by Trochim (2006) as an expert sample, and by Saunders et al. (2015) as a homogenous sample.

The goal of purposive sampling is to identify a limited number of individuals who can provide valuable information to the researcher. Due to an individual's specific role or experience, a researcher may personally invite them to be part of the sample. Individuals within the sample may, themselves, suggest additional individuals who may be added to the sample. The addition of individuals to the sample based on the recommendation of members of the sample population is often called snowball sampling and is often combined with purposive sampling (Johannesson & Perjons, 2014).

3.2.6.5 Sampling Techniques – Selection and Summary

The primary research strategy used in this project was the development and refinement of a framework, which represented a DSR artefact and fulfilled the research aim. To this end, the primary data collection and analysis techniques for the project were related to the development, testing, and refinement of the framework.

Saunders et al. (2015) suggest that purposive sampling is appropriate for use when a sample is chosen with a purpose in mind. In the context of this research, a purposive sampling method was used to facilitate the development, refinement, and validation of the DSR artefact. Due to the scale and scope of the architecture and facility management professions in the United States, it would be difficult, if not impossible, to generate a representative sample. Also, because the initial phases of the research project supported the development of the DSR artefact – and later its refinement and validation – a purposive sample was appropriate. Members of the proposed purposive sample were targeted based on their perceived ability to provide valuable information related to the development and validation of the framework. Professional architects, engineers, and facility managers were specifically targeted who had experience working on design and construction projects which involve facility managers in building maintenance and operation.

3.3 Research Onion Summary

Table 3.4: Research methodology rationale

Saunders et al. Research Onion Research Methodology – Selection and Rationale Summary		
Research Onion Category	**Category Selected**	**Selection Rationale**
Philosophy	Pragmatism	Supports mixed methods in pursuit of finding a practical solution for the identified problem.
Approach to theory development	Abduction	Enables a back-and-forth in theory development, taking advantage of both induction and deduction approaches.
Methodological choice	Mixed methods	Supports the qualitative and quantitative nature of the study. Facilitates robust results that are stronger than can be gathered by using a single method.
Strategy(ies)	Design science	Allows for the development of a functioning artefact that addresses the aim.
Time Horizon	Cross-sectional	Time constraint associated with a PhD thesis and typical AECO project timeline.
Techniques and Procedures		
• Data collection	1. Interview 2. Survey 3. Validation Interviews	1. Gathers opinion of working AE/FM professionals in a deductive manner. 2. Allows for an expanded respondent pool in a qualitative and quantitative manner. 3. Allows for refinement and validation of proposed design science artefact.
• Data analysis	1. Thematic analysis 2. Descriptive statistics	1. Allows for analysis of open-ended text-based data collection. 2. Allows for analysis of large amounts of quantitative data from an online questionnaire.

3.4 Ethical Considerations

There were no unique or unusual ethical considerations associated with this research study. Data collection focused on semi-structured interviews, surveys, and validation interviews. Interview and survey questions were not personal or confidential in nature. All participants were fully capable adults and participated of their own free will. Prior consent was provided by all respondents prior to participation (See Appendix B for Ethics Approval).

3.4.1 Code of Ethics

This project was not funded by, or associated with, an outside agency that has its own code of ethics. Although not funded by, or directly associated with, the code of ethics established by the American Institute of Architects, of which the author is a member, helped shape the study and the study's ethical approach.

3.5 Chapter Summary

This chapter presented the selection of the research methodology that supported the study. The Saunders et al. (2015) Research Onion was used as a model to describe and justify the choices adopted in developing the research project. The study's philosophical underpinnings, approach to theory development, methodological choice, research strategy, time horizon, data collection procedures, and data analysis techniques were identified and justified. The following chapter, Chapter 4, describes the research design, discusses issues of reliability and validity, and outlines steps taken to ensure both within the context of the study.

4. RESEARCH DESIGN

4.1 Chapter Introduction

Chapter 3 presented the selection of this study's research methodology and its rationale; however, detailed descriptions of the DSR strategy and data collection techniques used were not presented. This chapter discusses the DSR strategy and data collection techniques used in greater detail and explains the design of the interview questions and survey questionnaire. Data analysis and associated discussions are presented in the following chapter.

4.2 Design Science Research Strategy

As DSR was the primary research strategy used in this thesis, it is expanded on here after being introduced in Section 3.2.4.

March and Smith (1995, p. 256, as cited in Ralph & Wand, 2009), describe DSR as an approach to research that "builds and evaluates constructs, models, methods and instantiations" with "design intent". However, while both design and DSR appear to be very similar with regards to design intent, and they both focus on the development of artefacts and are concerned with novelty, according to Johannesson and Perjons (2014, p. 8), they differ with respect to their "generalisability and their contribution to knowledge." Whereas design may produce works relevant to a local practice or realm, DSR intends to develop and communicate new knowledge of broader, more global, interest (Johannesson & Perjons, 2014).

These differences of purpose create three additional requirements that must be addressed by DSR, but which are not essential elements of design. According to Johannesson and Perjons (2014), DSR must:

1. Make use of rigorous research methods;
2. Be related to an existing field of research and associated knowledge base to ensure research outcomes are well-founded and original; and
3. Be communicated to a broader audience of practitioners and other researchers.

van Aken (2005) further describes the goal of DSR as the development of new knowledge, which professionals in the field(s) associated with the research can use and implement in their practices. It produces descriptive, explanatory, and predictive knowledge. This process of knowledge generation manifests itself in the design, building, and application of an artefact

(Hevner et al., 2004). Markus et al. (2002) additionally find that producing an artefact as a part of the DSR process helps researchers better understand the problem before them.

Expanding beyond the three principles of Johannesson and Perjons (2014) from above, Hevner et al. (2004, p. 82) identify seven DSR guidelines. According to Hevner et al., DSR requires:

1. **Design as an artefact**: Design science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.
2. **Problem relevance**: The objective of design science research is to develop technology-based solutions to important and relevant business problems.
3. **Design evaluation**: The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
4. **Research contributions**: Effective design science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and design methodologies.
5. **Research rigour**: Design science research relies upon the application of rigorous methods in the construction and evaluation of the design artefact.
6. **Design as a search process**: The search for a practical artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment.
7. **Communication of research**: Design science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Hevner et al. (2004, p. 92) identify utility as the fundamental question of DSR. They ask: "What utility does the new artefact provide?" and "What demonstrates that utility?" Design science research and associated evidence must address these two questions. Without utility, there is no contribution from the research; and if existing methods are adequate, then new artefacts are unnecessary.

Table 4.1: Summary of the main concepts of design science

Design Science Key Concepts	
Definition of Design Science	Science that seeks to consolidate knowledge about the design and development of solutions, to improve existing systems, solve problems, and create new artefacts.
Artefact	Something that is manmade, and interface between the inner environment and the outer environment of a given system.
Satisfactory Solutions	Solutions sufficiently appropriate for the context in question; the solutions should be feasible to the reality and does not necessarily need to be optimal solutions.
Classes of Problems	Organisation that guides the trajectory and development of the knowledge in the design science context.
Pragmatic Validity	Seeks to ensure the utility of the solution proposed to the problem; considers cost/benefit of solution, specificities of the environment in which it will be applied and the actual needs of those interested in the solution.
(adapted from Dresch et al., 2015)	

Where traditional academic research describes phenomena within existing realities, rather than prescribing a solution to change reality (Kehily & Underwood, 2015), DSR facilitates the proposal and evaluation of new ways of working (that is to say, new realities). This research process identifies an issue and then proposes and evaluates an artefact that addresses the identified issue (Figure 4.1 and Section 1.2.6).

Figure 4.1: Conceptual research process

Through the development of artefacts, within a cyclical development and evaluation research process, DSR accommodates the development of new processes and technologies. In the context of this research, this process is used to develop solutions that facilitate information sharing between FM/O and AE-design teams.

In integrating a DSR approach into the study's mixed methods context, the project fulfilled three conditions necessary in a DSR strategy:

1. The project established an overall research strategy for investigating the problem situation and for eliciting stakeholder requirements. This includes a variety of research methods for data collection: interviews, questionnaires, and validation interviews. Strategies are also identified to analyse generated data. This data analysis was used in the generation and evaluation of an artefact.

2. The project situated generated results within the existing built environment knowledge frameworks and artefacts, which made it possible to assess its originality and validity.
3. The project will disseminate its results to both researchers and professionals through publication of the thesis, focus groups, and similar events. This dissemination will situate the work within the local practice in which it is developed while being generalised across a global built environment practice.

(adapted from Johannesson & Perjons, 2014, p. 9)

The DSR strategy used in this research relied on a mixture of qualitative and quantitative techniques to fulfil the DSR requirement of rigorous methods. Semi-structured interviews, an online questionnaire, and validation interviews with practising professionals were used to support the development, refinement, and validation of a DSR artefact that provides utility and fulfils the research aim.

4.3 Research Process

The research process undertaken for this study consisted of three primary data collection procedures described in the sections below. The development of the DSR framework represented an additional research activity described in Chapter 1, which was concurrent with and influenced by these three data gathering activities.

A conceptual framework that fulfils the research aim was developed through a literature review and semi-structured interviews with facility managers and AE designers. An online questionnaire was then used to confirm and validate the assumptions made in the conceptual framework. The framework was then refined and expanded upon based on the findings from the questionnaire. At the end of the study, the framework was further refined and validated through a series of semi-structured validation interviews with working AE and FM professionals. These data collection procedures are expanded on below while the process as a whole is represented in Figure 4.2.

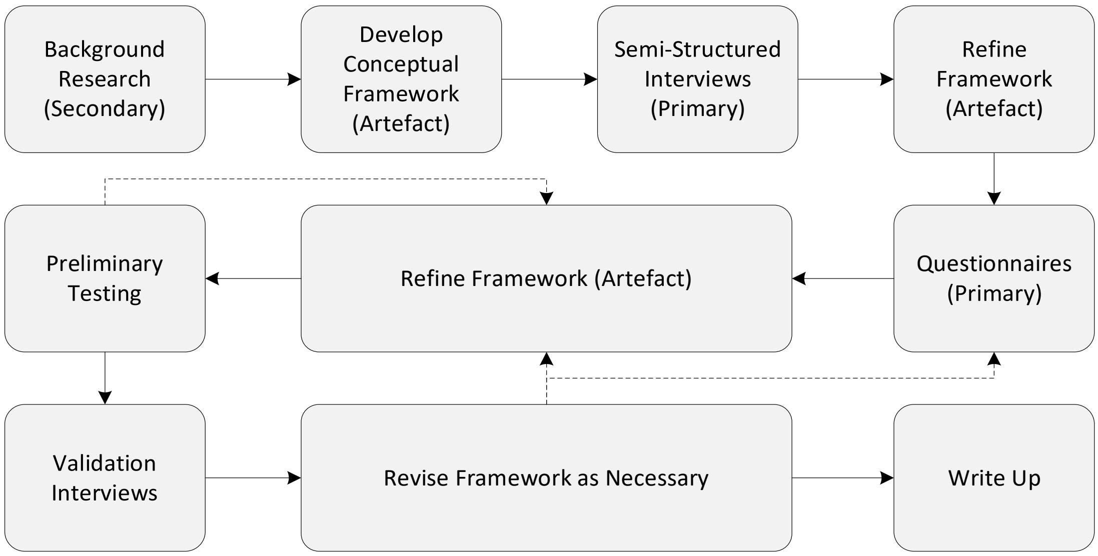


Figure 4.2: Research process flow diagram

4.4 Purpose of Semi-Structured Interviews

According to Saunders et al. (2015), when used as part of an exploratory study, in-depth interviews can provide the necessary background and context for a study. Saunders et al. further suggest that interviews can help identify questions and assist in designing subsequent research questionnaires. Semi-structured interviews were used in this study as an exploratory phase of the research to explore findings from the literature review, to provide context from working practitioners, to contribute to the specification of the research's focus, and to aid in the development of questions for a more widely dispersed subsequent online questionnaire.

4.4.1 Sampling of Interview Respondents

As discussed in Chapter 3, purposive and snowball sampling were used in this phase of the research project to select AE and FM/O professionals with relevant professional experience. For the interview phase of this study, 20 participants were recruited with the goal of completing 10 to 12 individual interviews. The purpose of this phase of the study was to expand foundational knowledge acquired during the literature review to provide an additional basis for the initial development of a framework that fulfilled the research aim. A purposive sample size of 20 was based on work by Guest, Bunce, and Johnson (2006), who suggest that data saturation occurs after 12 interviews in qualitative research studies. Saunders et al. (2015, p. 297) further indicate that the minimum non-probability sample size for semi-structured interviews is 5 to 25 persons.

Interview participants were contacted directly by the researcher. The author identified individuals from his personal and professional contacts. They were selected to provide an overview of architecture/engineering and facility management professions in the United States, focusing on the Mid-West in keeping with the scope of the thesis. Participants were recruited based on their professional experience and awareness of FM and AE professions. Interviewees were selected who had experience with design and construction projects that involved institutions or clients who had facility management operations. Architecture and engineering respondents were only chosen if they had worked on design projects with clients with facility management operations, and facility management respondents were only selected if they had been involved in projects with an A/E design component.

4.4.2 Development of Interview Questions

Interview prompts were developed abductively; that is, questions were both designed inductively and deductively. Questions for the interviews were developed inductively based on informal, unstructured interviews with other researchers and practitioners and based on the researchers existing body of knowledge. At the same time, additional questions were developed deductively based on findings from the literature review. Interview questions and their connection to the literature review findings can be seen in Table 4.2 below.

Table 4.2: Semi-structured interview questions linked to literature review findings

Interview Question General Purpose and Connections to Literature Review Findings			
	Semi-Structured Interview Questions		
#	**Background Information**	**Lit. Review**	**General Purpose of Questions**
1	Please briefly describe the company or institution for which you work and your current role(s)?	-	Asked to determine the demographics of the interviewees.
2	How long have you worked professionally? How long have you worked in your current position?	-	
3	How aware are you of the facility management (or A/E) design profession?	-	
4	How often do you work on design, construction, or refurbishment projects that have a facility manager? (or) As a facility manager, how often do work on design, construction, or refurbishment projects?	-	
5	Based on your professional experience, how would you describe the relationship between A/E design teams and facility managers?	-	
Information/Data Tracking			
6	Do any of the companies for which you have worked (or currently work) keep a database of 'lessons learned' from past projects? If so, what type of information/data do you track and how is the database kept?	5	Asked to gather information about interviewees' decision making and information and data tracking processes.
7	Do any of the companies for which you have worked use a process for documenting key project decisions and/or requirement changes? If so, what is their process for documenting decisions or changes?	5	
8	If you currently work in FM/O, or have worked, did/does the company or institution for which you work(ed) use any Performance Measurement Tools? (e.g., POE, Business Excellence Model, Balanced scorecard, KPI, Benchmarks) If so, which tools are/were used?	1, 5	
9	If you currently work in FM/O, what facility data or related information do you currently track (i.e., what benchmarks or KPIs)? How is this information tracked and stored? If you currently work in A/E, what data or related information would you like to receive from FM/O? How, and in what form, would you like to receive the data/information?	1, 5	
Relationships between FM/O and Design			
10	What role, if any, do you think facility managers should have in A/E design processes?	2, 3	Asked to gather information about interviewees' views on the topic of sharing information, data, and knowledge between FM and AE-design teams.
11	Do you believe it would be helpful during the design process to provide design teams with historical operational data and information from existing facilities? Why or why not?	2, 4	
12	In your experience, based on past projects, how would you describe the availability of FM data to A/E design?	4, 5	
13	What FM/O data/info do you think would be valuable for design teams to be made aware? During what project phase do you think it would be most beneficial to provide this data?	1, 4, 5	
14	What barriers do you think limit the consideration of existing FM/O data/info during design?	All	
15	During which design phase(s) do you think it would be most beneficial for facility managers to be involved in design decision-making processes?	2	
16	What do you think can be done to increase facility manager participation in design?	All	
17	To what extent do you believe the digital exchange of data and information is sufficient to realise the benefits of FM inclusion in design (that person-to-person interaction is not necessary)?	2, 4, 5	
BIM Related			
18	How often do you utilise BIM authoring tools or related software on projects (e.g., Revit, ArchiCAD, Bentley Systems)? Which do you use?	5	Asked to gather opinions on the potential for BIM platforms to facilitate improved AE and FM information transfer.
19	As a result of BIM, have you updated phase specific project requirements (e.g., project checklists, required deliverables)? How, why, or why not?	5	
20	If you currently work in FM/O, or have worked, does the company or institution for which you work maintain Asset Information Models (AIM), or equivalent? If so, how is the model maintained? / If not, why not?	5	
Conclusion			
21	Would you like to add anything to what we have discussed today?	-	

Proposals to Promote FM-Design Integration – Literature Review Findings

1. Codify FM knowledge
2. Create a defined role for FM in the design process or on the design team
    a. Include contract requirements to include FM in design
    b. Conduct regular design review meetings with FM
3. Improve FM competencies through better training
4. Improve communication between designers and FMs
5. Use technology to make data from past projects more accessible and shareable
    a. Improve FM knowledge management software
    b. Use IOT and databases to act as a repository of institutional knowledge
    c. Use BIM, GIS, or platforms to transfer data between FM and design teams

4.4.3 Semi-Structured Interview – Data Collection Procedures

Twelve semi-structured interviews were conducted (Table 4.3). Each participant signed and returned the Consent Form associated with the study's ethics approval (Appendix B). Eleven of twelve interviews were conducted in person, and one interview was conducted over the phone. Interviews were approximately one hour in duration and generally followed the sequence of questions in the associated semi-structured interview prompt.

Table 4.3: Semi-structured interview participants

Semi-Structured Interview Participants			
Interviewee Identifier	**Interview Length**	**Interviewee Background**	**Work Experience** (Types of projects and organisations)
I-1 FM	01:01:25	Facility Management	Public university
I-2 AE	01:28:10	Architectural Design	Regional AE firm
I-3 FMAE	00:27:59*	Architectural Design and Facility Management	Regional AE firm and experience as an FM at a large, global hospitality company
I-4 AE		Architectural Design	Regional AE firm
I-5 AE		Architectural Design	Regional AE firm
I-6 FM	00:53:34	Facility Management	Global hospitality company
I-7 FMAE	01:38:47	Architectural Design and Facility Management	Retired architect and professor of facility management
I-8 FMAE	00:52:49	Engineering Design and Facility Management	Building engineer for global food production company
I-9 FM	01:56:10	Facility Management	FM for global furniture company
I-10 FM	00:24:08	Architectural Design	Regional AE firm
I-11 FM	01:09:00	Facility Management	Public university
I-12 FMAE	01:25:48	Engineering Design and Facility Management	Mechanical engineer and FM for multiple US government agencies
*Interview was conducted in a group setting. Interviewees were asked each question separately and given the opportunity to respond individually before moving on to the following question.			

The researcher digitally recorded each interview. Although the name of each participant was recorded in the Participant Information Sheet, and the names of the organisations were in some instances inadvertently stated in the interviews, to preserve the respondents' anonymity, identifying questions or comments were avoided to keep each recording anonymous and identifiable information was not included in the data analysis, nor included anywhere in this thesis in keeping with the ethical requirements of the University.

Audio files were saved as "Interview -1", "Interview -2", et cetera, to maintain anonymity. A separate handwritten document was retained by the author linking specific interviewees with their respective recordings. In this manner, the identity of each interviewee cannot be directly linked to the digital recordings except by the author, thereby facilitating anonymity. Recording files for each interview were transferred from a digital recording device directly to the author's computer. The files were deleted from the recording device after being transferred from the digital recording device. These files were then uploaded to an online transcription service, Temi.com. At no time during transferring or transcribing the files were interviewee identities associated with a specific file. Due to the naming procedure used, only the author can link an individual interviewee to an audio file.

Once uploaded to Temi.com, Temi's computer-automated transcription service transcribed each interview recording. Because Temi uses artificial intelligence and machine learning for its speech recognition, files on its server are not seen or read by a human. Similarly, other Temi users cannot see the files unless the author shares them. All files uploaded, stored, and transmitted by Temi are also encrypted using TLS 1.2 encryption. Once files are deleted from a Temi account, they are permanently deleted from their servers (Temi, 2017). To facilitate interviewee anonymity, uploaded audio recordings included no identifying information.

Temi's automated transcription provided a time-stamped text file for each recording. These transcriptions were generally accurate, but they did contain some errors. The Temi interface allows a user to play the audio of a recording while corresponding words in the transcription are highlighted. This allows a user to hear what was said while verifying the accuracy of the transcript. If Temi is not confident in the accuracy of the transcription, words are colour-coded in the transcript. This allows the user to see questionable transcriptions quickly and easily. The user interface also allows the user to correct any transcription errors directly online. This was done for each transcribed interview. After each file was uploaded to Temi's cloud-based server, the transcription file was reviewed for highlighted errors. To ensure the accuracy of the transcription files, the researcher reviewed each file and associated errors by listening to the corresponding recording while correcting mistakes in the transcription. These transcription files were then downloaded to the author's laptop and deleted from Temi's servers. During this process, interviewee names were not associated with an audio recording file or text-based transcription file.

4.4.4 Semi-Structured Interviews – Data Analysis Techniques

Semi-structured interview transcripts underwent analysis using a qualitative thematic approach to data analysis. The thematic analysis approach was based on recommendations by Braun and Clarke (2006) and their suggestion for six phases of thematic analysis (Table 4.4). Highlights from this analysis are reviewed below.

Table 4.4: Phases of thematic analysis

Phases of Thematic Analysis (adapted from Braun & Clarke, 2006 p. 87)	
Phase	**Description of the Process**
1. Familiarise yourself with your data	Transcribe data (if necessary), read and re-read the data, noting down initial ideas.
2. Generate initial codes	Code interesting features of the data in a systematic fashion across the entire data set, collate data relevant to each code.
3. Search for themes	Collate codes into potential themes, gather all data relevant to each potential theme.
4. Review themes	Check if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2); generate a thematic 'map' of the analysis.
5. Define and name themes	Ongoing analysis to refine the specifics of each theme and the overall story the analysis tells. Generate clear definitions and names for each theme.
6. Produce a report	The final opportunity for analysis. Select vivid, compelling extract examples, final analysis of selected extracts, relate the analysis back to the research question and literature, produce a scholarly report of the analysis.

Interview responses were coded broadly based on the types of questions answered. After this initial coding, the interviews were re-coded in a more refined manner based on several themes identified in the initial coding and during the review of the transcriptions. After the second round of coding, the codes were collated into potential themes. These themes were reviewed in relation to the coded extracts from the complete data set to identify themes.

In keeping with the work by Braun and Clarke (2006) discussed above, the specifics of these initial themes were refined through further analysis to reduce thematic overlap (Phases 3 and 4, Table 4.4). This led to the generation of clear definitions and names for each theme (Phase 5, Table 4.4). These final themes were then elaborated on in the data analysis sections below, with representative excerpts provided from the interviews. Coded quotes corresponding to each theme were documented and provided in Appendix D.

4.5 Purpose of Online Survey

In contrast to the deductive approach used in the interview stage, an inductive approach was used through a questionnaire that collected descriptive and exploratory data to build additional knowledge regarding the best way to address the research aim. This approach was based on the suggestion from Saunders et al. (2015) that a researcher may wish to employ interviews in the exploratory stages of a research project to gain a better understanding of key issues, followed by a survey or questionnaire to collect additional descriptive or exploratory data.

A conceptual framework was initially developed based on the literature review and subsequent semi-structured interviews. The development of the framework was further supported through an online questionnaire shared with practising AE-design and FM/O professionals. This questionnaire included both quantitative and open-ended qualitative questions. The data collected from this online questionnaire was then used to further develop and refine the framework. In addition to seeking to add to the body of knowledge on its own, the purpose of the survey was, therefore, to help validate findings from the interviews and the initial conceptualisations of the DSR framework, and to then provide additional, refined data, for inclusion in the framework.

4.5.1 Sampling of Survey Respondents

For the selection of survey respondents, a non-probability, purposive sampling approach was used. According to Robson (2015, p. 279), non-probability sampling is commonly used in small-scale surveys and is "acceptable when there is no intention or need to make statistical generalisations to any population beyond the sample surveyed." Within non-probability sampling, there are multiple sampling techniques available. It is sometimes combined with snowball sampling, where the respondents themselves suggest additional respondents to add to the sample (Johannesson & Perjons, 2014). For this study, the primary sampling technique used was purposive sampling, with snowball sampling used to expand the respondent pool.

According to Saunders et al. (2015), non-probability sampling is often used when the sample being selected is chosen to illustrate particular aspects or make generalisations to a theory rather than to make generalisations about a population. Saunders et al. (2015) further suggests that in non-probability sampling, data saturation is not necessary, and that data saturation may be inappropriate for some research, for example, where the purpose of the study is intended to "establish whether something is possible" (317).

Johannesson and Perjons (2014, p. 43) describe purposive sampling as a "useful technique for generating an exploratory sample" with the goal of identifying a limited number of individuals who can provide "especially valuable information to the researcher." These purposively selected individuals may have valuable knowledge or experience about the research topic based on their experiences or professional roles. For these reasons, the researcher may personally ask them to participate in the study (Robson, 2015).

Potential respondents were targeted from within the author's professional and academic contacts. When the questionnaire was started, the author taught in the US in an architecture and facility management program situated within a School of Built Environment. This position provided access to alumni and advisory boards for four different degree programs: Architecture; Facility Management; Construction Management; and Heating, Ventilation, Air-Conditioning, and Refrigeration. The applicant also had industry contacts from more than 20 years of architectural design practice. These groups were used as the primary recruiting pools for potential participants. In addition, AE and FM professional organisations in the US, of which the lead applicant is a member, were used for recruiting participants through their respective local chapters, forums, and knowledge communities.

Approximately 300 potential survey respondents were targeted directly with an email asking them to take the survey. This was done with the hope of achieving a 30% response rate. This anticipated response rate was based on the work of Baruch and Holtom (2008), which suggests that for most academic studies involving individuals or representatives of an organisation, a response rate of 35% – 40% can be seen as a reasonable expectation. The target sample size of 300 was selected based on the goal of achieving 100 completed responses. According to Breen, Breen, Dutka, and Alan (1998), for populations over 5,000 to be 95% confident that a sample result is within a 10% margin of error, a random sample of 97 would be required. Given that the nature of the survey was to deduce trends and infer results in an exploratory manner in support of the DSR framework, a 95% confidence rating with a 10% margin of error was seen as acceptable. In addition, according to Pinsonneault and Kraemer (1993) (see also Dresch et al., 2015; Forza, 2002), with an exploratory survey, a representative sample is not a requirement and a sample size only need be large enough to include a part of the phenomenon of interest (see Table 4.5).

Table 4.5: Minimum dimensions of survey studies by purpose

Element/Dimension	Exploration	Description	Explanation
Research design			
Survey type	Cross-sectional	Cross-sectional	Cross-sectional and longitudinal
Mix of research methods	Multiple methods	Not necessary	Multiple methods
Unit(s) of analysis	Clearly defined	Clearly defined and appropriate for the questions/hypotheses	Clearly defined and appropriate for the research hypotheses
Respondents	Representative of the unit of analysis	Representative of the unit of analysis	Representative of the unit of analysis
Research hypotheses	Not necessary	Questions or hypotheses clearly stated	Hypotheses clearly stated
Design for data analysis	Not necessary	Inclusion of antecedent variables and time order of data	Inclusion of antecedent variables and time order of data
Sampling Procedures			
Representativeness of sample frame	Approximation	Explicit, logical argument; reasonable choice among alternatives	Explicit, logical argument; reasonable choice among alternatives
Representativeness of the sample	Not a criterion	Systematic, purposive, random selection	Systematic, purposive, random selection
Sample size	Sufficient to include the range of the phenomena of interest	Sufficient to represent the population of interest & perform statistical tests	Sufficient to test categories in theoretical framework with statistical power
Data Collection			
Pre-test of questionnaires	With subsample of sample	With subsample of sample	With subsample of sample
Response rate	No minimum	60 – 70% of targeted population	60 – 70% of targeted population
Mix of data collection methods	Multiple methods	Not necessary	Multiple methods
(adapted from Pinsonneault & Kraemer, 1993)			

The survey was administered online between May to December 2019. At the close of the survey, 144 respondents had started the survey, and 127 valid respondents had completed the survey. When reduced to US based AE and FM respondents, this number became 101 valid responses (50 AE specific respondents and 51 FM specific respondents respectively). The number of respondents met the goal of 100 respondents. It is impossible to calculate a response rate from this email targeting effort as the author is aware that several responses came from respondents who had the email shared with them indirectly. The email sent to the targeted respondents asked if they would share the survey with anyone in the AE or FM profession whom they thought might complete the survey.

4.5.2 Development of Survey Questions

The questionnaire was structured to address the five key areas of further inquiry, which came from the thematic analysis of the semi-structured interviews discussed in Chapter 5, Section 5.2.3. Survey questions and their connection to these semi-structured interview areas of further inquiry can be seen in Table 4.6 below.

Table 4.6: Online questionnaire questions linked to interview findings

Survey Question General Purpose and Connections to Interview Findings			
#	Online Survey Question Summaries	Area of Inquiry*	General Purpose of Questions
1	Participant's Statement of Informed Consent	0	Asked to determine the demographics of the respondents and the appropriateness of their responses to contribute to the survey.
2	Which of the following most accurately describes your position?	0	
3	How long have you worked professionally?	0	
4	In which of the following geographic areas do you primarily work?	0	
5	In which of the following industry sectors do you primarily work?	0	
6	Which of the following professional credentials do you hold?	0	
7	How aware are you of the facility management profession?	0	
8	How aware are you of the architecture/engineering design profession?	0	
9	Have you been involved in a new-build construction project or major renovation/refurbishment within the last five years?	0	
10	How often have you worked on design, construction, or refurbishment projects that include the involvement of a facility manager?	0	
11	If you currently work in a facility management related role or have worked in one, does/did the company or institution for which you work maintain Asset Information Models of your facilities?	4, 5	Asked to gather information about respondents' decision making and information and data tracking processes.
12	Do any of the companies for which you have worked utilise a formal design decision-making process such as Lean, Choosing by Advantages (CBA), Six Sigma, Target Value Design (TVD), Axiomatic Design, Instinct Driven Approach (IDA), etc.?	1	
13	If you answered yes, how are/were design decisions documented?	1	
14	Do any of the companies for which you have worked keep a database of lessons learned from past projects?	3, 4	
15	If you answered yes, in what form was/is this database kept?	3, 4	
16	What do you think would be the ideal method for keeping a record of lessons learned from past projects?	3	
17	Do any of the companies or institutions for which you have worked use a process for documenting key project or design decisions and/or requirement changes?	3, 4	
18	What do you think is the ideal method for documenting key project or design decisions and/or requirement changes?	3	
19	Based on your professional experience, what facility management/operations related data or information do you believe would be most helpful to provide from FM to A/E design?	1	Asked to gather information about respondents' views on the topic of sharing information, data, and knowledge between FM and AE-design teams.
20	How useful would the following facility management/operations data categories be to A/E design teams during the design process?	1	
21	Do you agree or disagree: The digital exchange of facility data and information would be sufficient to realise the potential benefits of facility management inclusion during design (that person-to-person interaction is not necessary)?	3, 5	
22	Do you agree or disagree: A/E design rationale provided to facility management and operation teams would be beneficial to the facility operation and maintenance process?	1	
23	Do you agree or disagree: Awareness of the rationale behind facility design decisions is necessary to effectively evaluate a facility's performance and design quality?	1	
24	During which project stages would it be most useful to transmit data and information from FM/O to AE-design teams?	2	
25	During which project stages would it be most useful to transmit data and information to facility management/operations from architecture/engineering design teams?	2	
26	How familiar are you with the following building systems classification systems?	4	Asked to gather information on respondents' views of the potential for existing building classification systems to facilitate improved information transfer between AE and FM.
27	Which of the following building systems classification systems do you regularly use?	4	
28	To what extent do you think the following represent an effective method for transmitting information between FM/O and AE-design?	3	
29	Which of the following mechanisms do you think would encourage the transfer of data and information between FM/O and AE-design?	3, 4, 5	
30	Do you have any other thoughts related to the involvement of FM in the AE-design process that you would like to share?	1, 2, 3, 4, 5	

*Areas of inquiry identified through semi-structured interview findings (see section 5.2.3)

0. General demographics question
1. What information from FM would benefit AE-design teams?
2. When should information from FM be provided to AE-design teams?
3. In what form should information from FM be provided to AE-design?
4. How can information be classified to make it useable to external parties?
5. Can digital measures help facilitate the involvement of FM in AE-design?

4.5.3 Online Survey – Data Collection Procedures

The online questionnaire was proctored using the online questionnaire service, SurveyMonkey.com. Participant consent was integrated into the survey and consent was required by all respondents prior to beginning the survey (Appendix E). If consent was not given, the respondent was unable to complete the survey. All survey responses were kept anonymous. Emails were not required to be provided, nor were they tracked by SurveyMonkey. However, ISP addresses were tracked by SurveyMonkey to ensure the survey was only completed once per respondent. These ISP addresses were only tracked by the hosting service and were not provided to the researcher.

At the end of the survey, respondents were asked if they would like to receive a summary of survey responses and be informed of the outcome of the research project. If respondents selected *Yes*, they were taken to a separate survey where they were asked to provide an email address. This second survey was fully isolated from the original survey, and any emails provided cannot be associated with a specific survey response. This method allowed respondents to share their email and to receive updates on the research while maintaining anonymity of their specific responses. At the close of the survey, 44 out of the 144 respondents asked to be informed of future work related to the research and to have its findings shared with them.

4.5.4 Online Survey – Data Analysis Techniques

Survey responses were analysed using deductive thematic analysis for open-ended questions. Where possible, descriptive statistics for Likert items were used to compare FM respondents with AE respondents. Descriptive statistics were used to identify statistically significant results between these two groups. These results are used to validate findings from the literature review and semi-structured interviews in support of the development of the DSR artefact.

Statistically significant difference calculations were used to identify when FM vs AE responses were substantially and reliably different. Within the data presented in the following chapter, statistically significant differences are highlighted in orange. When results are not highlighted, it indicates that they were not statistically different. However, that does not mean results of other items were unimportant or that statistically different results were important. According to Freund, Mohr, and Wilson (2010), it is possible to "have a statistically significant result that has no practical implications." It is also possible to "not have a statistically significant result, yet useful information may be obtained from the data." To aid in the interpretation, the differences are discussed in the discussion associated with each question.

The statistical significance calculation was calculated using a 95% confidence level from within the two groups being compared (AE vs FM respondents). When a statistically significant result was found, it meant the difference between the compared respondent groups had less than a 5% probability of occurring by chance. The formulas used to calculate the statistical significance can be seen in Appendix G.

4.6 Purpose of Validation Interviews

Validation interviews were held to solicit the views and opinions of the working professionals regarding the ease of comprehension and applicability of the proposed DSR framework. Furthermore, opinions were sought on the relevance and usability of the individual components of the framework, as well as how the proposed framework could be refined to address the needs of the industry more effectively. After receiving feedback on the artefact from these interviews, the artefact was refined.

4.6.1 Selection of Interview Respondents

Interview participants were contacted directly by the researcher. Individuals were identified by the author from his personal and professional contacts. They were selected to provide an overview of architecture/engineering and facility management professions in the United States. Participants were recruited based on their professional experience and awareness of FM and AE professions. Interviewees were selected who had experience with design and construction projects that involved institutions or clients who have facility management operations. Architecture and engineering respondents were only chosen if they had worked on design projects with clients with facility management operations, and facility management respondents were only selected if they had been involved in projects with an A/E design component. The respondents, therefore, had relevant experience in the AE-design profession, FM/O profession, or in some cases, they had direct experience in both. All the respondents interviewed worked at the time in either the AE or FM/O profession in the Mid-West region of the United States, thus providing the views of practising professionals within the targeted scope of the thesis (Table 4.7).

Table 4.7: Validation interview participants

Validation Interview Participants			
Facility Management Participants (FGFM)		Architecture / Engineering Participants (FGAE)	
Participant Code	Professional Responsibility	Participant Code	Participant Role
VI-1 FM	Facility Manager	VI- 6 AE	Engineer
VI-2 FM	Facility Manager	VI-7 AE	Architect
VI-3 FM	Facility Manager	VI-8 AE	Architect
VI-4 FM	Facility Manager	VI-9 AE	Architectural Designer
VI-5 FM	Facility Manager	VI-10 AE	Architect

4.6.2 Validation Interviews – Data Collection Procedures

Notes were taken, and sketches and diagrams were made by the researcher and interviewees participant(s). In addition, meetings were recorded to provide transcripts of meetings for review. Participants were provided with an initial overview of the framework described in Chapters 7 and then presented with the individual components. Towards the end of the validation process, participants were also presented with a proof-of-concept web application discussed Chapter 8. Their feedback was documented in written notes and with recordings of conversations. Where appropriate, feedback was incorporated into the proposed framework. In this manner, these validation interviews were used to validate and refine the DSR artefact.

4.7 Research Reliability

Saunders et al. (2015) describe research reliability as the extent to which data collection techniques lead to consistent findings and whether other researchers would make similar conclusions or observations. Trochim (2006) adds that reliability represents the consistency or repeatability of your measures, and that reliability cannot be calculated, only estimated.

While some argue that research quality should be measured against the criteria of reliability and validity, Saunders et al. (2015) find that standard measures to assess research quality are based on quantitative, positivist assumptions that are not necessarily philosophically and technically appropriate for qualitative research based on interpretive assumptions. Saunders et al. (2015) further add that “qualitative research is not necessarily intended to be replicated because it will reflect the socially constructed interpretations of participants in a particular setting at the time it is conducted" (p. 205). By rigorously describing the research design, context, and methods, subsequent researchers will be better able to replicate similar studies. Elo and Kyngas (2008) add that to increase the validity of a study, it is important to demonstrate links between the results and the data. They further suggest that in doing so, "the researcher must aim at describing the analysing process in as much detail as possible when reporting the results" (p. 112).

Acknowledging that there is no consensus regarding the issue of reliability in qualitative research, Saini and Shlonsky (2012, p. 115) suggest three methods that can help ensure qualitative research reliability:

1. Use of representative quotes to support themes;
2. Demonstration of consistency of themes and quotes; and
3. Transparency of the research process.

This study adopted the suggestions of Saini and Shlonsky to help ensure its reliability. As seen in Chapter 5 and 6 below, this study used quotes and examples to support themes and concepts which emerged from semi-structured interview data and open-ended survey questions. Because the interviews represented a qualitative approach, and subsequent survey data, in part, represented quantitative data, this study represented a mixed method approach. A mixed method approach allowed survey results to complement and support findings that arose from earlier semi-structured interviews and the initially proposed framework. The themes and findings that emerged from the surveys and interviews, which were embedded in the revised framework, were then confirmed through validation interviews. In adherence to Saini and Shlonsky's final recommendation for increased reliability, the study sought to ensure its transparency by attempting to plainly and accurately describe the research methodology and findings.

4.8 Research Validity

Research validity refers to the extent to which data collection methods accurately measure what they are intended to measure or the extent to which research findings describe what they profess to be about. Research validity, therefore, refers to the appropriateness of the research measures used, the accuracy of the corresponding analysis, and the generalisability of a study's findings. Saunders et al. (2015) suggest two methods that help establish the validity of a research study:

1. Triangulation; and
2. Participant or member validation

Triangulation refers to using or combining multiple data sources, data collection procedures, and data analysis techniques (Tashakkori & Teddlie, 2003). According to Saunders et al. (2015), triangulation necessitates either a multi-method quantitative study, a multi-method qualitative study, or a mixed methods study (Table 4.8). Triangulation's purpose is to use two or more independent data sources and data collection methods within a single study to interpret the data.

Table 4.8: Methodological choice options

Methodological Choice (Saunders et al., 2015)	
Mono Method Quantitative	Utilises a single data collection technique, such as a questionnaire, and a corresponding quantitative analytical procedure.
Multi-Method Quantitative	Utilises more than one quantitative data collection technique and a corresponding quantitative analytical procedure.
Mono Method Qualitative	Utilises a single data collection technique, such as a semi-structured interview, and a corresponding qualitative analytical procedure.
Multi-Method Qualitative	Utilises more than one qualitative data collection technique and a corresponding qualitative analytical procedure.
Mixed Method	Combines the use of quantitative and qualitative data collection techniques and associated analytical procedures.

Participant or member evaluation refers to the process of sending research data back to participants to confirm its accuracy. Participant validations are essential in some qualitative research strategies such as action research but may be difficult in quantitative approaches, particularly those that ask for anonymity.

In this research study, a literature review, semi-structured interviews, an online questionnaire, and validation interviews were utilised to provide multiple data sources that support the development of solutions that facilitate information sharing between FM/O and AE-design teams. Because each of these represented an acceptable form of data collection in a mixed methods approach, their combined use increased the reliability and validity of the study. Further consistency was provided by the fact that the conceptual framework emerged from the literature review and semi-structured interviews. An online questionnaire was then utilised to confirm the findings from the literature review and semi-structured interviews. The online questionnaire further tested the ideas of the conceptual framework. Data collected from the questionnaire was then used to develop and refine the framework, which in turn was validated through validation interviews. Within this process, each research phase grew organically out of the previous and, in total, demonstrated consistency in themes and findings.

4.9 Chapter Summary

This chapter discussed the DSR strategy and data collection procedures and explained the design of the interview questions, survey questionnaire, and validation interviews. Data analysis and associated discussions are presented in the following chapter. In conclusion, this chapter discussed issues of reliability and validity and outlined steps taken to ensure both within the context of the study. The next chapters describe data analysis for the semi-structured interviews and online questionnaire.

5. INTERVIEW DATA REVIEW AND ANALYSIS

5.1 Chapter Introduction

This chapter presents results from the semi-structured interviews based on the coding as adapted from Braun and Clarke (2006) and interpretations of the data are presented.

5.2 Interview Analysis Thematic Coding

Interviewee responses were initially coded broadly based on the types of questions answered. This initial coding included the following question categories:

1. Interviewee background information,
2. Information and data tracking,
3. Relationships between FM/O and AE-design, and
4. Building information modelling (BIM).

After the initial coding, the author determined the codes were too broad to be useful as many questions elicited responses discussing multiple themes. The interviews were then re-coded in a more refined manner based on several themes identified in the initial coding and during the review of the transcription files. Subsequent codes were identified as:

1. FM-AE relationship – general,
2. FM-AE relationship – respect,
3. FM-AE relationship – professional awareness,
4. Benefits of FM involvement in design,
5. Barriers to FM involvement in design,
6. Data and information sharing,
7. Decision tracking,
8. Institutional knowledge, and
9. Added value.

After the second round of coding, these codes were collated into potential themes. These themes were reviewed in relation to the coded extracts from the full data set. A series of initial themes arose from this collation and were identified as follows:

1. There is a perceived benefit from both FM and AE respondents of increased FM involvement in AE-design processes.
2. A lack of awareness of FM's body of knowledge on the part of both professions presents a barrier to FM involvement in AE-design.
3. Facility managers should be involved throughout the design process, but involvement during early stages is perceived as particularly valuable.
4. Inability to share institutional knowledge both internally and externally presents a barrier to FM involvement in AE-design.
5. Inability to share institutional knowledge, both internally and externally, acts as a barrier to tracking and assessing design decisions.
6. The digital transfer of data, information, and knowledge from FM to AE-design teams alone is insufficient. Some person-to-person interaction would be necessary to explain the digital knowledge transfer.
7. There is a lack of professional respect between both professions.
8. There is a general lack of awareness from both professions regarding what the other profession does or how they work.
9. Despite Theme #1, there is a general lack of awareness from both professions regarding what information would be beneficial to share.
10. Knowledge management failures hinder the ability to share data and information, both internally and externally.

5.2.1 Semi-Structured Interviews Themes

Based on the work by Braun and Clarke (2006) discussed in Section 4.4.4, the specifics of these initial themes were refined through further analysis to reduce thematic overlap (Phases 3 and 4, Table 4.4). This led to the generation of clear definitions and names for each theme (Phase 5, Table 4.4). These final themes are elaborated in the sections below, with representative excerpts provided from the interviews. The final six themes are summarised in Table 5.1. Coded quotes corresponding to each theme are provided in Appendix D. In addition, to aid in understanding the development of the themes, a diagram that conceptually maps the coding process is also provided in Figure 5.1.

Table 5.1: Summary of semi-structured interview themes

Semi-Structured Interview Themes			
Themes		Mentions	Respondents who Mentioned Theme
1.	Unrealised benefit of FM involvement during the design process	10/12	I-1 FM, I-2 AE, I-3 FMAE, I-4 AE, I-5 AE, I-6 FM, I-9 FM, I-10 AE, I-11 FM, I-12 FMAE
2.	Lack of interdisciplinary awareness and respect limits FM involvement in design	10/12	I-1 FM, I-2 AE, I-3 FMAE, I-5 AE, I-6 FM, I-7 FMAE, I-9 FM, I-10 AE, I-11 FM, I-12 FMAE
3.	Lack of decision-making processes and decision tracking limits knowledge sharing	11/12	I-1 FM, I-2 AE, I-3 FMAE, I-4 AE, I-5 AE, I-6 FM, I-7 FMAE, I-8 FMAE, I-9 FM, I-10 AE, I-12 FMAE
4.	Poor knowledge management limits knowledge sharing	11/12	I-1 FM, I-2 AE, I-3 FMAE, I-4 AE, I-5 AE, I-6 FM, I-7 FMAE, I-8 FMAE, I-10 AE, I-11 FM, I-12 FMAE
5.	FM involvement should be focused early but ongoing	11/12	I-1 FM, I-2 AE, I-3 FMAE, I-4 AE, I-5 AE, I-6 FM, I-7 FMAE, I-8 FMAE, I-9 FM, I-10 AE, I-12 FMAE
6.	Digital and face-to-face knowledge sharing is necessary	11/12	I-1 FM, I-2 AE, I-3 FMAE, I-4 AE, I-5 AE, I-6 FM, I-8 FMAE, I-9 FM, I-10 AE, I-11 FM, I-12 FMAE

5.2.2 Semi-Structured Interviews Themes – Discussion and Excerpts

According to Braun and Clarke (2006), *themes* capture something significant within the data concerning the research aim or question. Furthermore, themes represent some level of *patterned* response within a data set. They suggest that a theme is ideally repeated numerous times in a data set, but more repetitions of the theme in the data do not necessarily mean a theme is more important than others. The *keyness* of a theme is also not necessarily dependent on quantifiable measures, such as the number of times it appears in the data, but rather on how well it captures something important in relation to the research aim or question.

Working with this background from Braun and Clarke, the initial themes developed through the coding process discussed above are elaborated on below. Furthermore, in keeping with the discussion on Research Reliability addressed in Section 4.7, the use of representative quotes are used to support the identified themes and are provided to 1) support the identified themes; 2) help demonstrate the consistency of themes and quotes; and 3) ensure transparency of the research process (Saini & Shlonsky, 2012).

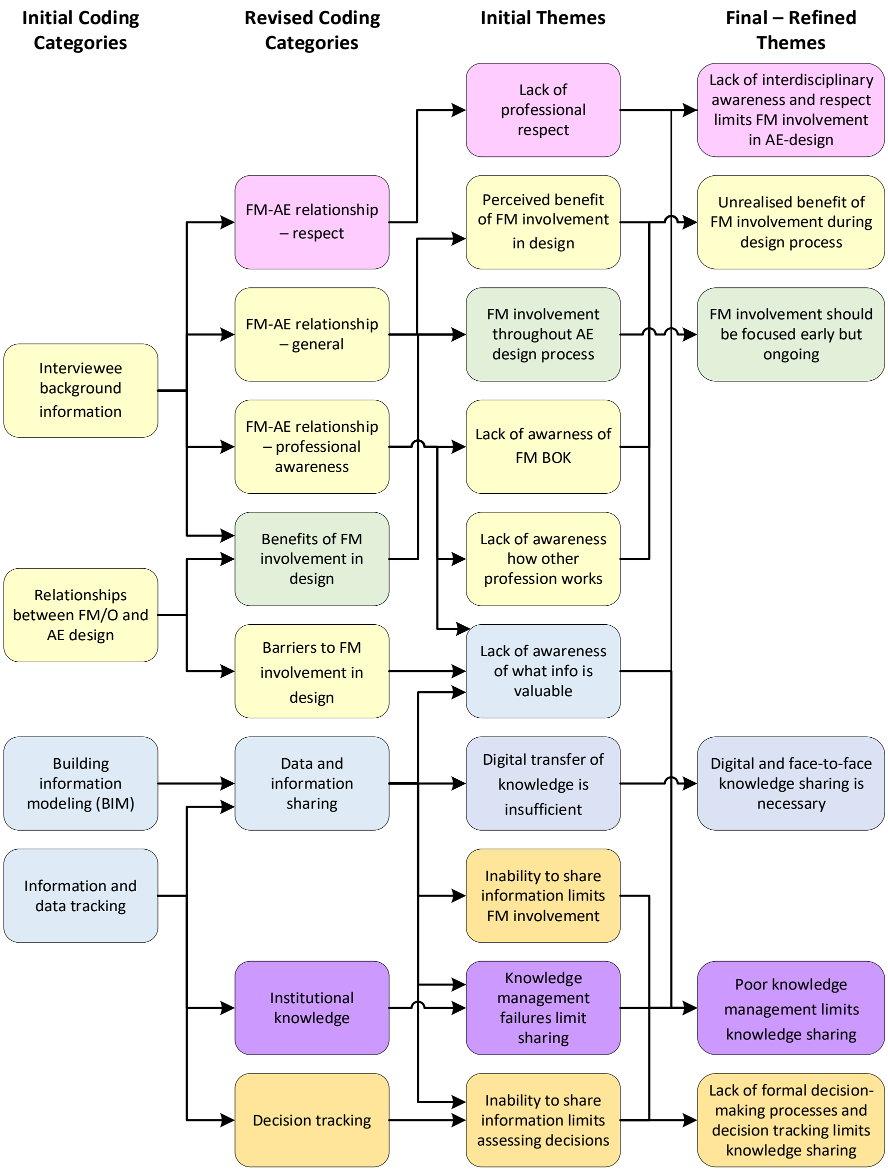


Figure 5.1: Conceptual mapping of the interview coding process

5.2.2.1 Theme 1: Unrealised Benefits of FM Involvement During the Design Process

Throughout the interview process, it was evident from 10 out of 12 participants that they perceived a benefit for FM to be involved in the AE-design process and that increased involvement would provide additional benefits. (The remaining two participants did not address the issue.) However, when asked to elaborate further on what that benefit might be or how FM might be more involved, respondents were less clear and less able to elaborate on what FM would, or could, bring to the design process. This lack of clarity was not universal, as some respondents had concrete examples of how FM could help design. For example, respondent *I-6 FM* shared several specific examples of how he thought FM could contribute to the design process. However, the respondent was less clear regarding the specifics of how such involvement would happen.

> **I-6 FM (21:32):** … **there's certain things in this building that you'll see that, I'll say this is going to be a nightmare, but every single room has it.** And for instance, like Barn Doors, we have sliding barn doors everywhere. Beautiful. I love them. They're really nice ones. They bought heavy duty ones. But if one kid slams that barn door, it's going to rip the hardware out of the ceiling. I already know what's going to happen.

> **I-6 FM (23:00):** …I have a lot of experience with meeting rooms and stuff. They don't, and **I can tell you which ones are going to be used a lot**. Which ones maybe they could have shared walls to make a bigger meeting room…

Interviewee *I-6 FM* was the most vocal and specific regarding how FM can add to the design process. This may have been because, at the time of the interview, *I-6 FM* was involved in the construction of a new hotel complex with an integrated conference centre and restaurant. In fact, the interview took place at the construction site, and *I-6 FM* provided a tour of the facility after the discussion. During this tour, *I-6 FM* repeatedly pointed out problems he perceived with the design and how he could have helped address the issues had he been involved in the design process.

> **I-6 FM (22:00):** …if somehow someone could keep track of how much money is spent on repairing things and if money would have been put in initially to just go with one standard, one step higher in quality that you would save money in the long run… **I can walk you through this building and tell you what's going to work and what's not going to work.**

> **I-6 FM (14:20):** …a lot of stuff you see it as it's coming in and **as they're making it and you're thinking, why on earth did they do that?** …I have some like VAV boxes that I have to do maintenance on that are eight feet above the ceiling and I can't even get to them. So, I'm gonna have to get a lift and a ladder on top of the lift to even reach them. **Where if I was involved early, you know, it's almost too late at some point to**.

While *I-6 FM* was the most vocal regarding the need for FM to be involved during the AE-design process and provided the most specific examples, other interviewees shared similar, albeit less direct, thoughts.

> **I-1 FM (14:32):** I've seen too many times where [I] go back through and see something that we probably could have picked out as being odd and something that could have been prevented or, you know**, we have information that just a normal designer, or A/E firm wouldn't. I wish, they worked more together**.

I-2 AE (1:21:26): … **there is no validation of our assumptions as designers**. Now that client may have learned over the years that this works and this doesn't, so maybe that client has a little bit of a database but, at a design firm, you know, you have started, you make these assumptions and now you make it 15 more times that year alone because you've got that many projects. You know, like it's uh, I think, **I think the FM has the ability to start to fill in those gaps.**

I-9 FM (35:12) (speaking of the design and construction process): In my opinion, **seasoned facility project managers make the best 'conductors' of this symphony**.

I-10 AE (6:01) (speaking about the role of FM in design): … going beyond facility manager position down below like just like talking to people like the cleaning staff that are dealing with a building on a day-to-day basis… **figuring out what could be more effective for them and where things aren't working out as they would like them to.**

(6:36) [There] should be a seat at the table. I feel like they should be reviewing designs and all of the key phases and **giving us feedback on things we can do to improve.**

I-12 FMAE (20:35): …we've been very successful and in fact we have been so successful that most of the projects that we've been executing the last year-and-a-half **have been based on feedback that we've received from the operators, from facility managers because they see, they understand the building**.

In general, responses suggested a bias that FM involvement in the design process would most benefit functional aspects of the design process. This raises a question about the ideal timing of FM involvement in the design process, as a functional bias may suggest FM involvement in early, conceptual design stages is unnecessary. Rather, it may be more relevant in later stages when descriptive specifications are made. The question of the timing of FM involvement in design, and the theme in general, is further explored in Theme 5 below and the subsequent online questionnaire.

The comments of I-6 represent an additional potential bias in the views of the interviewees. Interviewee I-6 was in the process of finishing the construction of a new facility and making it operational. It was clear this made design questions and his lack of involvement in the design process prevalent in his mind. Similarly, each interviewee is likely to focus on the value of their own profession. Facility managers deal daily with the results of design decisions. It can be expected that they would perceive the value of their tacit knowledge as high regarding its potential to inform future design decisions. Similarly, AE-design professionals are likely to value their profession highly and question the need for the involvement of others as doing so could potentially bring into question their professional knowledge and value. These potential biases do not diminish the value of the responses but must be recognised.

5.2.2.2 Theme 2: Lack of Interdisciplinary Awareness Limits FM Involvement in AE-Design

Despite the perceived benefits of FM involvement in AE-design, the comments from 10 out of 12 interviewees suggested a lack of full awareness of how the other discipline works and what information they might want or be able to share. (The remaining two participants did not address the issue.) This seemed more pronounced in the interviews with AE respondents. Multiple AE interviewees suggested they would like to receive data and information from FM but were unsure what information they would want or what information FM could provide.

The general inability of FM respondents to identify what information they have that would be beneficial to AE-design teams indicates they (FMs) may not have a data collection and analysis approach. It may similarly suggest a lack of detailed awareness of the AE-design process and an inability to identify what information would be valuable and when (see quote I-11 FM (29:47) below). These possibilities are further explored in the subsequent online questionnaire.

There also seemed to be a subtle lack of respect between disciplines, which may be due to the apparent lack of knowledge of the other field. The lack of respect portion of this theme is primarily based on the perception of the author from his experience conducting the interviews and from interviewees' tones of voice and non-verbal cues, rather than from specific quotes in the transcripts. This observation appears to present a contradiction to interviewee responses when asked about their awareness of the AE or FM professions. Each respondent indicated they were aware of the other profession, but this did not seem to manifest itself in a meaningful awareness of how the other profession functions or what types of knowledge and information they might want or have access to.

> **I-1 FM (18:01):** I don't think they realise… I know things are changing now with facility management, you know, being involved but I think that a lot of people that we work with are older firms and they're still kind of stuck in that rut of not consulting the FM**… I think for some people it definitely is egos. …I've seen that with some of the oldest firms that we work with**. I think the middle, we don't work with very many young, we don't work with very many old, but the middle, I think they just don't know. I know it

wasn't really, I think it was around them, **but it wasn't as well-known what FM is**. There wasn't a real name, you know, facility management wasn't a name for it.

I-2 AE (34:47): …**most designers don't know anything about facility managers.** So, they wouldn't necessarily know what to ask for.

I-5 AE (19:16): …**they're not included in any of the conversations.** So, we don't even know. **We don't even know if they have one.**

I-9 FM (54:01): ...I'm not sure that practitioners [designers] really understand how people work [building users].

I-11 FM (29:47) (discussing whether FMs have information worth sharing with AE teams): I'm sure there is, but specifically**, I don't know what would be, what would work best for them?**

I-12 FMAE (19:03): … often times the importance of facility management is overlooked and, and another very important item that needs to be taken into consideration is the fact that **facility managers are often looked as inferior to architectural/engineering design teams** because traditionally a facility manager doesn't have educational background in architectural engineering.

As a result, …**they're not able to often clearly articulate what the problem is even though the issue might be a valid concern.**

5.2.2.3 Theme 3: Lack of Formal Decision-Making Processes and Decision Tracking Limits Knowledge Sharing

Eleven out of 12 interview participants suggested their organisations do not generally utilise a formal decision-making process. (The twelfth interviewee did not address the issue.) However, the participants generally indicated their belief that using a formal decision-making process or formal decision tracking process would be beneficial and would potentially provide opportunities for FM knowledge and insight to be added to the design process. It would also help the FMs confirm if the AE teams are using the information provided to them.

I-1 FM (8:29): …we had a firm work on campus that ended up doing a horrible job after they were done with the work. We actually had to hire someone else to come in and fix their mistakes. And then we hired them again for another project and we were let down again. And so, **we realised that they didn't do anything with the information we gave them**.

I-2 AE (1:09:16): I know on the design side that **having something, physical to record design decisions would be very beneficial** and produce less headaches for me.

5.2.2.4 Theme 4: Poor Knowledge Management Limits Knowledge Sharing

The analysis of the interviews thematically suggested poor knowledge management makes it difficult to share information, both internally and externally. Furthermore, poor knowledge management makes it difficult, if not impossible, to assess design decisions or project requirements. This theme was evident in 11 out of 12 interviews. (The twelfth interviewee did not address the issue.)

The failure of knowledge management was primarily manifest in two ways in the interviews: 1) design decision rationale and project requirement changes are poorly tracked or documented, and 2) much of the FM related information that might be helpful to AE designers is not accessible.

Both AE and FM interviewees suggested decision rationale or requirement changes are typically documented in emails, text files, handwritten notes, meeting minutes, or often only in the mind of an individual. This makes it difficult for others to access the information or be aware that it exists. In many cases, interviewees suggested if you did not know a piece of information or knowledge existed, it would be difficult to find or be aware of its existence. Furthermore, these forms of documentation make it difficult for information from one project to be used in another. Often it is necessary to ask someone with prior experience, and if that person were unavailable or no longer worked for the company, the information was lost or inaccessible. By not tracking or having access to why decisions were made or why requirements changed, it is difficult, if not impossible, to accurately assess the quality of a design decision or the impact of a requirement change. This also makes it difficult to provide relevant information or data to inform a design decision. If you do not know why a decision is being made, it is difficult to provide relevant information or ask for relevant information to support it. Or vice versa, if you do not have access to the information underpinning a design decision, it is hard to understand why that decision was made and to evaluate it properly.

FM respondents indicated that much of the FM information that might be helpful to AE-design teams is not stored in an accessible manner or is not stored outside the mind of specific individuals. This makes it difficult for FM to share knowledge and data with AE-design because if you do not know the information exists in the first place, it is difficult to share or ask for it.

This is an essential point when viewed through the lens of a community of knowledge or the *knowledge illusion* described by Sloman and Fernbach (2018). Design is a communal activity that is the product of a community and not a single individual. Due to a designer's bounded rationality, no one person can know everything there is to know about the design of a building, and the designer's ability to act does not depend solely on the knowledge that is in their head at any given moment; it depends on the knowledge they have access to when they need it. In a knowledge community, such as design, access to knowledge is as equally important as having the knowledge itself.

> **I-1 FM (3:52)**: …the construction manager keeps that sort of thing that you know, we can, we can meet with him and discuss and he'll kind of guide us towards what happened last time, but as one that we can access at any time, no.
>
> **I-1 FM (5:31)**: …he's really good about keeping all of his little scribbles, all of his personal notes from when we go back in. And…sometimes he has physical ones. He'll, like you said, you'll pull those notes out of a filing drawer or he'll say, well, I don't have this anymore, but I can tell you from my experience last time.
>
> **I-8 FMAE (7:58)**: …You have to know the project exists and you have to have rights and access to that…
>
> [**Interviewer:** But if you don't know another project exists, there's not an easy way for you to discover that?]
>
> **I-8 FMAE (8:39):** Right. And the projects are so broad. So, one of them, I mean it sounds stupid, but it is a barrier is like, so a lot of our projects, um, have some industry concerns for secrecy. So, they're named something totally unrelated to what the project is. Like, the recent projects are based on a Marvel character theme. So, a project grouped by, um, Marvel Cerebro, you know, and so if that terminology, it's used within the project team and if it gets out because we have lots of contractors working on it, nobody knows what it is. But that's also the problem. **If you weren't involved in that project, it's hard to map that.**

The following representative quotes relate to how knowledge regarding past projects and lessons learned is shared within their respective firms.

> **I-2 AE (20:11):** … it's more of a mental thing. Like, oh, I use this because it did work one time or I don't like this brick because, you know, I used it on a project, and it was crap…
>
> **I-3-AE (5:48):** No, I think that's just by word of mouth.
>
> **I-4 AE (5:52)**: We just every month "lessons learned for the month", and it's unhelpful. …no, and we have a meeting with our company and one guy says three lessons learned

from the month that are extremely specific to the project and it's very unhelpful for the rest of firm.

I-10 FM (3:02) (discussing tracking and sharing lessons learned): …lessons learned, like not specifically, you know, that's more just kept in the memory bank.

… in terms of, of lessons learned, I mean, you know, those are just usually discussed at meetings.

Interview 12 spoke at length about issues related to knowledge sharing between AE-design teams and FM. His input was particularly insightful as he was a credentialed engineer in both the US and the UK and worked as a supervisory engineer managing both AE-design and FM personnel.

I-12 FMAE (1:00:41): So generally speaking, record keeping I think is very poor in the facility management industry. Uh, they put like very little emphasis to it. And again, that's because I think, you know, people are not attending to emergencies, reactive repairs. And the last thing somebody wants to do is keep good records of what has transpired. You know, the last year because they're running from one emergency to another. Unfortunately, you know, like, **that doesn't provide enough information to educate better design decisions.**

…**something that could be avoided is not avoided because the data perhaps is there or perhaps it's documented but not documented well enough.** Or there's a lot of tacit knowledge that people, you know, like are **not willing to pass along because typically tacit knowledge is equal to job security.** They feel that if they're documented in such a way that everybody could do the job, they may run out of a job.

(1:20:46) …Cause there's a lot of time being wasted hunting for information that you can't really find. And often times facilities would get frustrated and say the heck with that, you know, we don't have anything on it.

5.2.2.5 Theme 5: FM Involvement Focused Early but Ongoing

Eleven out of 12 interview participants suggested they thought FM involvement would be best focused early in the design process, such as during Design Development phases. However, they felt that involvement should continue throughout the life of a design project. (The twelfth interviewee did not address the issue.) When asked when it would be best for FM to be involved in the design process, most respondents suggested Schematic Design (SD) or Design Development (DD) phases. However – in contrast to the answers to a specific, targeted question – throughout the general interview, most of the interviewees indicated the involvement of FM in AE-design should be ongoing. The author does not see this as a contradiction; instead, it correlates to the fact that projects ebb and flow with regards to the type of information required at different phases and FMs have a range of information, knowledge, and data that would be applicable at a range of times in a project timeline.

> **I-1 FM (20:53):** I think a lot of it will be **loaded in the front, but I think you don't want to overwhelm with information at the beginning because then they're just going to kind of dismiss it as, oh, they sent us a packet of information that we don't need**. Um, I think it would need to be phased in a sense that as you're moving through, because I think a lot of what the issue is as facility managers when we're working with an A/E firm, you know, we'd give them what we've developed. They give us what they've developed and there's not a lot of us both being there at the same time kind of thing. Um, **being involved through that whole process and being able to relay that information as we go**…
>
> **I-2 AE (48:59):** Yeah, I would say starting at design development. Even some level in schematic design, but definitely design development, construction documents.
>
> (35:25) I think, at a minimum level, they should be reviewing drawings, at major milestones within the client. …and I think at a minimum level the facility manager should be involved in that process. Um, but, **at the same time, I think it would be much more beneficial to have them at the table, doing all the design meetings**, especially when it starts coming to uh, you know, like design development and you're starting to kind of figure out exactly where you're going when it comes to equipment or maybe not schematic design so much because that stuff's not, other than form, and kind of general direction.
>
> **I-9 FM (24:44):** It is important that the broad team have the appropriate engagement **during the entire process**.
>
> **I-10 AE (25:21):** I think you should have a major role at some point. I just don't know when that point would be…
>
> And probably the sooner the better because after the design is made and um, you know, calculations are completed, it, it might be already too late to, to change.

5.2.2.6 Theme 6: Both Digital and Face-To-Face Knowledge Sharing is Necessary

Eleven out of 12 participants suggested that both a digital and in-person exchange of information is necessary to transfer information from FM to AE-design effectively. (The twelfth interviewee did not address the issue.) When asked specifically about the digital exchange of information vs person-to-person exchanges, respondents were split on whether a digital exchange would be sufficient. This split can be seen in the representative quotes provided below. However, over the course of each interview, and from the tone of the interviewees, it was evident to the researcher that most interviewees felt *both* transfer mechanisms are essential – digital and interpersonal. The general feeling indicated that each transfer mechanism has its advantages and disadvantages, and by using both, the benefits of each can be realised.

> **I-1 FM (25:36):** I think it can be done digitally. I really do. …**I do think there is a benefit to, um, being on a personal basis, but there's no reason that it couldn't be done digitally if it's done correctly**.
>
> **I-2 AE (53:14):** I think a database, if it's maintained well and accurately will provide, **I think the information it provides would be better and more inclusive than a person to person talks, because you won't necessarily remember why you made certain decisions back in design development that have maintained throughout the whole project**. You will know why this changed to this during construction, so if you can turn to an all-inclusive location for information, again it is, the design team has to maintain it accurately**. Um, but if that were done, I think that would be much more useful to those people managing the facility. Yeah. Then just a sit-down and chat kind of thing**.
>
> **(24:43)** …another reason I think it's crucial is because if there is that intermediate stuff that you're hearing information from someone else, **the FM can be there to either verify or decide to get clarification**.
>
> **I-4 AE (23:50):** Uh, so I definitely think the data itself is important because it's a way to, uh, as a documentation of how things are actually happening. Uh, but I also think **it's important to be able to communicate with the person that is, uh, you know, managing the facility in terms of what they're frustrated with on a day-to-day basis or what the things they spend the most time on.** Because then that can lead to other solutions that might not come out of just looking at a spreadsheet.
>
> **I-5 AE (24:19): I think you need both of them simultaneously**. Um, where that digital data, the spreadsheets, you may interpret stuff differently than is actually the case where **the FM knows the day-to-day basis how things go, what the data actually comes down to and how like crucial that data is.**
>
> **I-6 FM (30:24):** I think you have it [information and data]. **You give it to them, you let them look at it and then I think that meeting has to be in place to explain what even they're looking at** because unless they've dealt with that industry, I think they might not even realise what they're looking at.
>
> [**Interviewer:** So, you think you would need both?]
>
> **I-6 FM (30:41):** Definitely.
>
> **I-9 FM (Written Notes):** Databases help incorporate existing operational functions into the design of a new building, but ownership comes from being involved in the decision process.

I-10 AE (9:25) (speaking of digital vs face-to-face interaction)**:** as a sole means of communication, I think it's inadequate. It's, there's so much information in the drawing set and in specs and everything, that stuff can very easily get lost. **So, I think you really need that [personal] interaction and double checking together.**

I-12 FMAE (1:08:45): I think both is very, very important. …based on what I've seen, the facility management team has to deal with day-to-day operation, as well as emergencies. Oftentimes, they don't have the time or perhaps they don't want to dedicate the time to sift through digital information or information that's provided to them in writing.

I think a combination of both is very important. You exchange those ideas [digitally]. But you have that in person, perhaps like sit down where you walk them through [it] and perhaps… as you're getting more used to that model of exchanging information that day-to-day human interaction is reduced drastically. **But I think at the beginning [having both] is very important,** especially when you're trying to get a new technology accepted and understood.

When Theme 6 is viewed alongside Theme 4, which indicated a lack of meaningful awareness of how the other profession functions or what types of knowledge and information they might want or have access to, the type of information being transferred may influence the preferred transfer method. It is difficult to identify the ideal method for sharing information if the type of information being shared is unknown. The question of information transfer methods is further explored in the subsequent online questionnaire.

5.2.3 Semi-Structured Interviews – Summary and Conclusions

The semi-structured interviews discussed above were included in this research study to serve three purposes: 1) They were intended as a mechanism to confirm findings from the literature review; 2) the interviews were intended to act as a form of exploratory research to help develop questions for a more widely dispersed online questionnaire, and 3) to provide data to support the development of the framework associated with the research aim.

As a form of exploratory research, the results from the analysis of these surveys should be seen as *indicative* in nature instead of definitive. In summarising the findings from this review of the semi-structured interviews, the author finds the interview data indicates the following conclusions:

1. There is an unrealised value of including FM in the AE-design process. This confirmed findings from the literature review.

2. Despite the perceived value of FM involvement in AE-design, it is unclear how this involvement can be best integrated into existing workflows.
3. Knowledge, information, and associated data within both AE and FM professions are maintained in a manner that makes it difficult to share or track.
4. The research aim and objectives have validity.

Furthermore, the findings from the interview data suggested a need to further investigate the following themes in the subsequent online questionnaire:

1. What information would be most beneficial to share between FM and AE-design?
2. When should information from FM be provided to AE-design teams?
3. In what form should information from FM be provided to AE-design?
4. How can FM and AE information be classified and stored to make it useable to external parties?
5. Can digital measures help facilitate the involvement of FM in AE-design?

While not directly related to one of the themes discussed above, in conclusion to this portion of the research, the author found the following interview quotes summarised the value of facilitating improved interaction between FM and AE designers.

> **I-6 FM (15:12):** …if it's a building that needs a lot of maintenance, like a hotel or a hospital, I think that relationship's probably, I can't really think of, I mean obviously the owner wants it to look a certain way. But besides the looks, the aesthetics of it**, I think that relationship** (FM-AE relationship) **is probably the most important, 'cause they know how it runs. The building needs to work.**
>
> **I-2 AE (32:15)**: … the one thing that would be beneficial is what type of information they do track. And, and just then like in the category. **So, you know as the designer, what has an importance in this company.** You know, like if it's sustainability in terms of helping the environment is not a key thing, but you know, tracking how our energy bill is, then you can tailor your conversations in that area.
>
> **(34:09)** Yeah. I do think that that would help **knowing what they track would help tailor your questions to ask for something from the client or um, you know, asking this in general things like how to properly speak their language about your design even**.

6. QUESTIONNAIRE DATA REVIEW AND ANALYSIS

6.1 Chapter Introduction

This chapter presents results from the questionnaire and interpretations of the data.

6.2 Online Questionnaire – Data Collection and Responses

Question 1: Respondent consent

Question 1 asked respondents to give their consent to take the survey. The consent form provided was approved in the study's ethics application (Appendix B). Of the 144 respondents to Question 1, 143 agreed to provide consent, and one declined.

Question 2: Respondent background

Table 6.1 shows the general characteristics of the respondents to the online questionnaire. Out of 144 total responses, 127 were found to be suitable for data analysis. This was because 17 respondents skipped the questions asking about their professional experience. The author excluded these responses because, without an awareness of their background, their other responses could not be evaluated meaningfully.

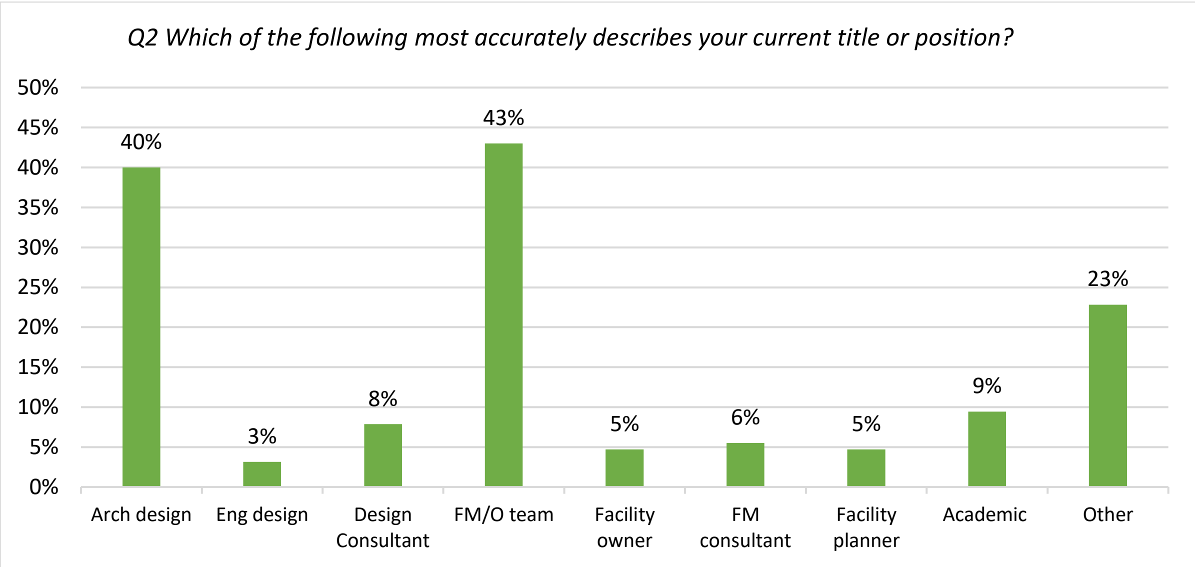


Figure 6.1: Respondent current title or position (all responses)

Of the 127 valid responses, 59 identified themselves as associated with the AE-design profession, 67 as associated with the FM profession, four associated themselves as working in the construction management profession, 12 identified themselves as associated with research/academics, and 15 associated themselves as *Other* (Figure 6.1 and Table 6.1).

Table 6.1: Characteristics of the respondents from the online questionnaire

Question 2: Which of the following most accurately describes your current title or position? (All responses)								
AE Design-Related			**FM/O-Related**			**Other**		
Architecture design team member (including interior design)	45	35.43%	FM/O team member	48	37.8%	Academic (Researcher or educator)	12	9.45%
Engineering design team member	4	3.15%	Facility owner	6	4.72%	Construction manager	4	3.15%
Design consultant	10	7.87%	FM consultant	7	5.51%	Project manager	1	2.56%
			Facility Planner	6	4.72%	Reality capture modeler	1	.79%
Other (AE related):			**Other (FM/O related):**			Sales/engineering	1	.79%
Urban planner/designer	2	1.57%	Asset manager	1	.79%	Telecom installation	1	.79%
BIM manager	1	.79%	State funding agency	1	.79%	Facilities user	3	2.36%
Former architectural technician	1	.79%	Government oversight authority	1	.79%	US Army Corps of Engineers	1	.79%
Retired architect and professor	1	.79%	Prior FM (career change)	1	.79%			
AE project manager	3	2.36%	FM project manager	3	2.36%			
Design director	1	.79%	Retired FM	1	.79%			
Total:	**68**	**54%**		**75**	**59%**		**24**	**21%**
Note: Totals add up to more than 100% because respondents had the option to select more than one answer – i.e., "all that apply."								

After the initial analysis of the respondent pool, questionnaire responses were further analysed to identify distinct populations within the sample. Through additional filtering and analysis of the data, the sample pool was reduced to two distinct groups: a group of AE-design-related respondents and a group of FM related respondents.

When individual AE and FM identifiers within the full respondent pool were combined accordingly, including any AE or FM related identifiers indicated under *Other*, 46% of respondents selected an AE-design-related identifier, and 53% selected an FM related identifier (Figure 6.2). The sum of these numbers added up to more than 127 because respondents could select *all that apply,* and many identified themselves as holding multiple titles or positions. The fact that respondents were almost equally split between AE and FM suggests an appropriate balance to the responses.

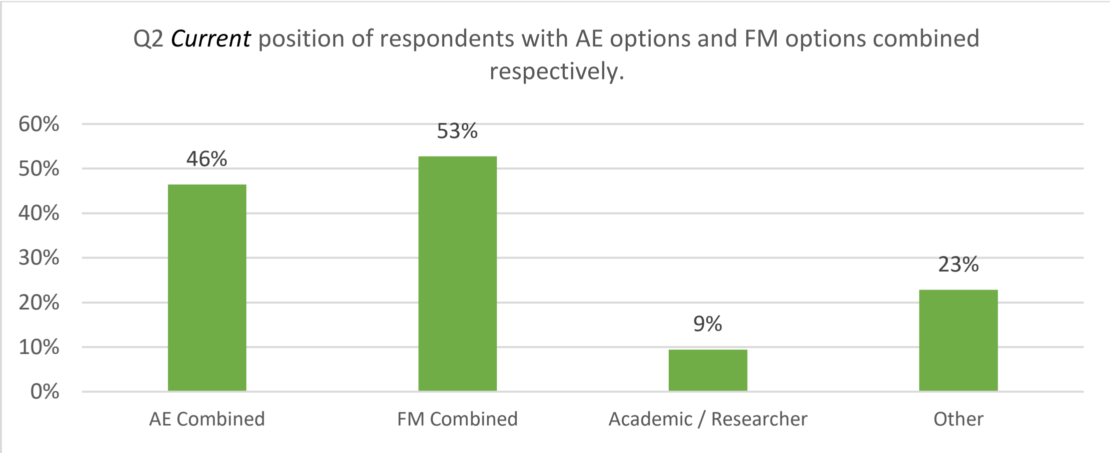


Figure 6.2: AE options and FM options combined

The initial pool of 127 respondents was then filtered by geographic location to show only those that worked within the United States. This was primarily done because the research sought to develop a DSR artefact within a local practice, within the United States. This filtering reduced the pool of responses from the initial 127 to 119. The analysis of the survey pool then sought to identify the remaining respondents as either being primarily related to AE, FM, or an overlap of both. This further analysis resulted in 101 valid US based responses – 50 associated with AE and 51 associated with FM/O (Table 6.2 and Table 6.3).

Initially 45 respondents identified themselves as an *architectural design team member*, 48 identified themselves as an *FM/O team member*, and 29 respondents identified themselves as *Other*. Of these 29 *Other*, six also identified themselves as an AE or FM/O team member with one working outside the US (in Ireland). This left 22 US responses to be reviewed for categorisation as either AE, FM or unrelated. Of this remaining 22 responses, eight could clearly be identified as being related to AE or FM/O based on the description of their current or past job, or their credentials. The remaining 16 were removed from the US only, AE – FM specific dataset either because their professional background could not be identified or was specifically unrelated to AE or FM. For example, urban planners and construction managers without clear AE or FM connections were removed from this refined data set. They were removed from the refined data set, not because their input was not relevant or unmeaningful, but to allow for analysis specifically between US AE and FM respondents. In the sections below, questions show responses for both the full data set, total US responses, and the refined US only AE-FM data set. However, data analysis and discussions were primarily limited to the refined AE-FM data set of 101 valid responses from the US.

Table 6.2: Total response pool – final breakdown

Question 2: Total Response Pool – Final Breakdown				
Response Pool	**Total # of Respondents**	**Self-identified Category**	**Responses per Category ***	**Responses per Category ***
Total relevant respondents	**127**	**Academic**	**12**	**9.45%**
		AE Related	**65**	**51.18%**
		FM Related	**73**	**57.48%**
		Other	**29**	**22.83%**
Total relevant respondent's (US Only)	**119**	**Academic**	**10**	**8.40%**
		AE Related	**62**	**52.10%**
		FM Related	**69**	**57.98%**
		Other	**27**	**22.69%**
AE filtered respondents (US only)	**50**			
FM filtered respondents (US only)	**51**			
*** Totals add up to more than 100% because respondents had the option to select more than one answer.				

It was anticipated that there would be overlap between the refined US based AE and FM groups, as respondents were able to select multiple categories to describe their professional background or current position. However, after analysis of each response within the refined data set, each response was able to be clearly identified as being related to either AE or FM. When limited to respondents who primarily work in the United States, this resulted in 50 (49.50%) responses associated with AE-design teams and 51 (50.50%) associated with FM (Table 6.2 and Table 6.3).

Like the breakdown of the full dataset, the fact that the refined pool was evenly split between AE and FM suggested an appropriate balance to the responses. In addition, as with the larger dataset, the refined number of 101 respondents specifically identified as either AE or FM met the target of 100 respondents discussed in the previous chapter. Where appropriate, in the questions below, this refined filtering was used to compare US respondents from AE vs FM. This was dependent on the specifics of an individual question and was addressed on a case-by-case basis.

Table 6.3: Respondent breakdown, United States only

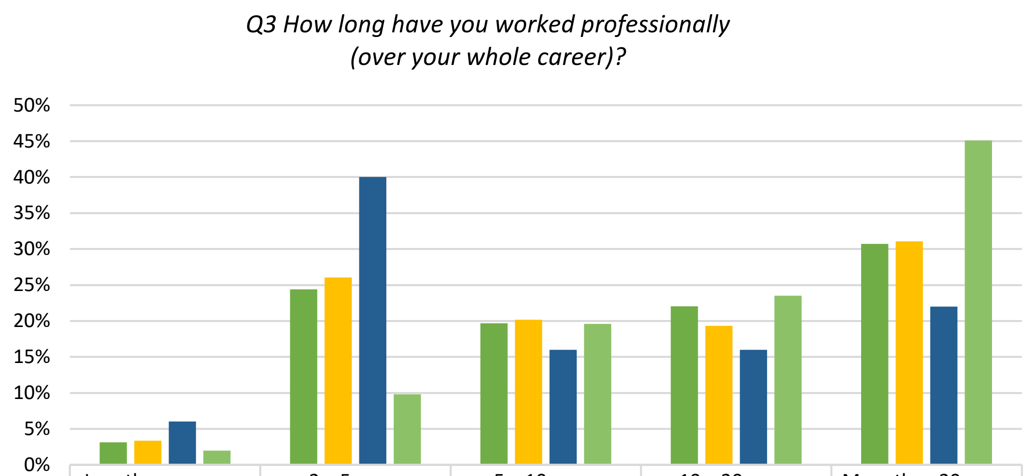
Question 2: "Other" Filtered					
Refined FM/O – AE Data set, United States Only					
	AE	**FM**	**Other**		
Initial Self Selection	**45**	48	24		
"Other" – as reassigned by researcher					**Researcher's rationale for excluding from the direct comparison dataset**
1			X	Construction Assistant Project Manager	Research is primarily focused on relationships between AE and FM/O.
2			X	Construction Manager - Estimator	Research is primarily focused on relationships between AE and FM/O.
3			X	Construction Manager, General Contractor	Research is primarily focused on relationships between AE and FM/O.
4			X	Construction Project Estimator/Manager	Research is primarily focused on relationships between AE and FM/O.
5			X	Facilities user	Non-specialised experience.
6			X	Home maker	Non-relevant experience.
7			X	Project Manager	Project type unspecified. Unable to determine relevance of experience.
8			X	Project Manager - Architectural Metals	Unable to determine project role.
9			X	Reality Capture Modeler	Non-relevant experience.
10			X	Sales/engineering	Non-relevant experience.
11			X	Telecommunications Installation	Non-relevant experience.
12			X	Urban Planner	Research is primarily focused on relationships between AE and FM/O.
13			X	Urban planner	Research is primarily focused on relationships between AE and FM/O.
14			X	BIM Manager	Respondent did not answer subsequent questions.
15		FM		Retired. Facility management, major capital project design and construction manager, LEED consultant and trainer	Recently retired FM.
16		FM		Asset manager, program assistant	Related FM work experience – manages non-profit, multi-family residential projects.
17		FM		Automotive Buyer/Project Manager. (Was an FM for 4 years before)	Recent job change from FM.
18	AE			State Funding Agency	Licensed architect
19	AE			Design Director	Works as design director for interior design team(s). NCIDQ credentialed.
20	AE			Government Oversight Authority	Licensed engineer
21	AE			Retired architecture professor and owner of an architectural firm.	Recently retired architect.
22	AE			Trade Contractor Operations Manager (former Architectural Technician)	Recent job change from architectural technician.
Filtered Respondents	**50**	**51**			

Question 3: Years of professional experience

Question 3 asked respondents how long they had worked professionally, over the course of their whole career, as opposed to only their current position. Responses indicate 3.15% of all respondents had less than one-year experience, 24.41% had between 2 – 5 years of experience, 19.69% between 5 – 10 years, 22.05% between 10 – 20 years, and 30.71% more than 20 years of experience. As can be seen from this breakdown, respondents represented a broad range of experience; however, 52.67% of the respondents had more than 10 years of experience.

When comparing the US AE-FM pool, 6% of AE respondents had less than one-year experience, 40% had between 2 – 5 years of experience, 16% between 5 – 10 years, 16% between 10 – 20 years, and 22% more than 20 years of experience. Within the US FM pool approximately 2% of respondents had less than one-year experience, 10% had 2 – 5 years of experience, 20% between 5 – 10 years, 24% between 10 – 20 years, and 45% more than 20 years of experience.

As can be seen from this breakdown, respondents represented a broad range of experience; however, most of the respondents had more than 10 years of experience. This suggests the data represents perspectives of experienced AE-design and FM professionals.



	Less than one year	2 – 5 years	5 – 10 years	10 – 20 years	More than 20 years
All	3%	24%	20%	22%	31%
US Only	3%	26%	20%	19%	31%
US AE	6%	40%	16%	16%	22%
US FM	2%	10%	20%	24%	45%

Figure 6.3: Length of professional career

Question 4: Respondent geographic work location

Respondents within the full dataset identified that they primarily worked in the United States (119), with a small number identifying that they worked in the United Kingdom (5). One applicant responded, under *Other* – that they worked *Worldwid*e. This showed a clear focus on work in the United States, which fit the purposive sampling method used for the survey. While this may limit the validity of the research to a specific geographic area this was seen as appropriate within a DSR strategy which sought to develop an artefact within a specific area of practice. This geographic focus was further amplified through the filtering described above. To be able to compare two distinct groups (US AE vs US FM), discussion of responses below is at times limited to responses from US and is indicated when done so. Only the full response pool is indicated in Figure 6.4 below as the refined pool was filtered to represent 100% US.

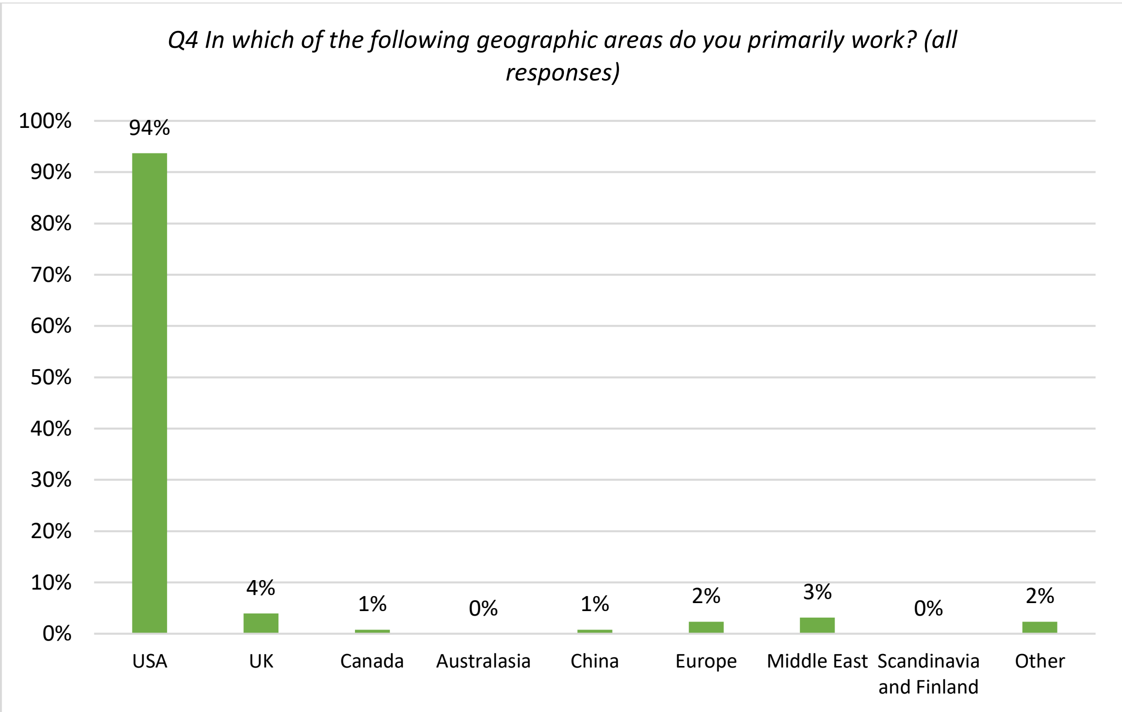
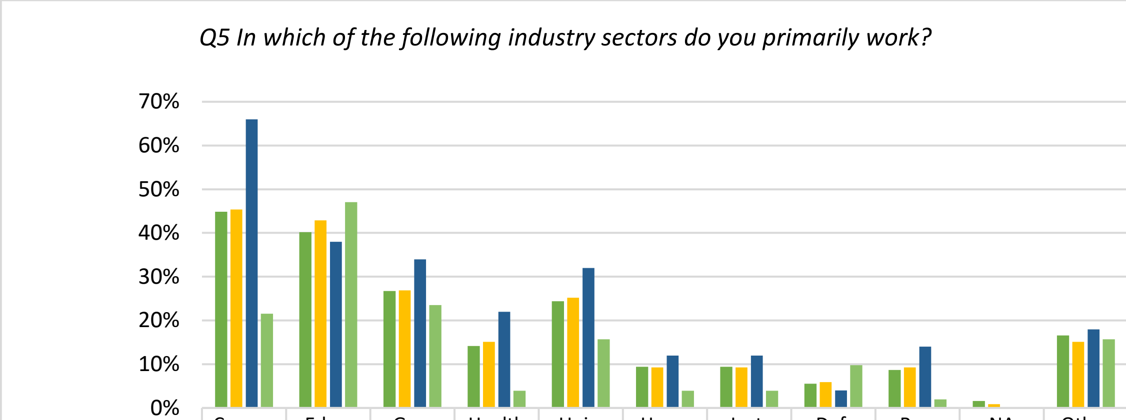


Figure 6.4: Primary geographic work area (all responses)

Question 5: Respondent industry work sector

Question 5 asked respondents to identify the industry sectors in which they typically worked. Responses suggested a range of sectors was covered by the respondents; however, most respondents worked in commercial, education, healthcare, and higher education.

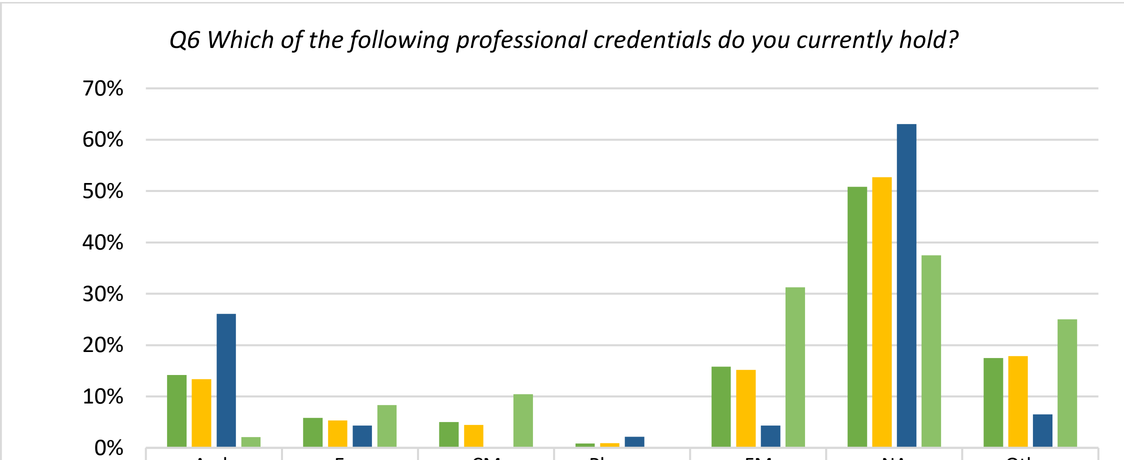


	Comm.	Educ.	Gov.	Health	Univ.	Hosp.	Inst.	Def.	Res.	NA	Other
All	45%	40%	27%	14%	24%	9%	9%	6%	9%	2%	17%
US Only	45%	43%	27%	15%	25%	9%	9%	6%	9%	1%	15%
US AE	66%	38%	34%	22%	32%	12%	12%	4%	14%	0%	18%
US FM	22%	47%	24%	4%	16%	4%	4%	10%	2%	0%	16%

Figure 6.5: Primary industry work sector

Question 6: Respondent professional credentials

Question 6 asked respondents to identify their professional credentials. Within the US AE-FM responses, 47 (46.5%) indicated *not applicable*, and 46 in total (45.5%) indicated they hold one or more related professional credentials. This number (45.5%) was determined by including credentials entered under *other* that relate to the AE-FM professions.

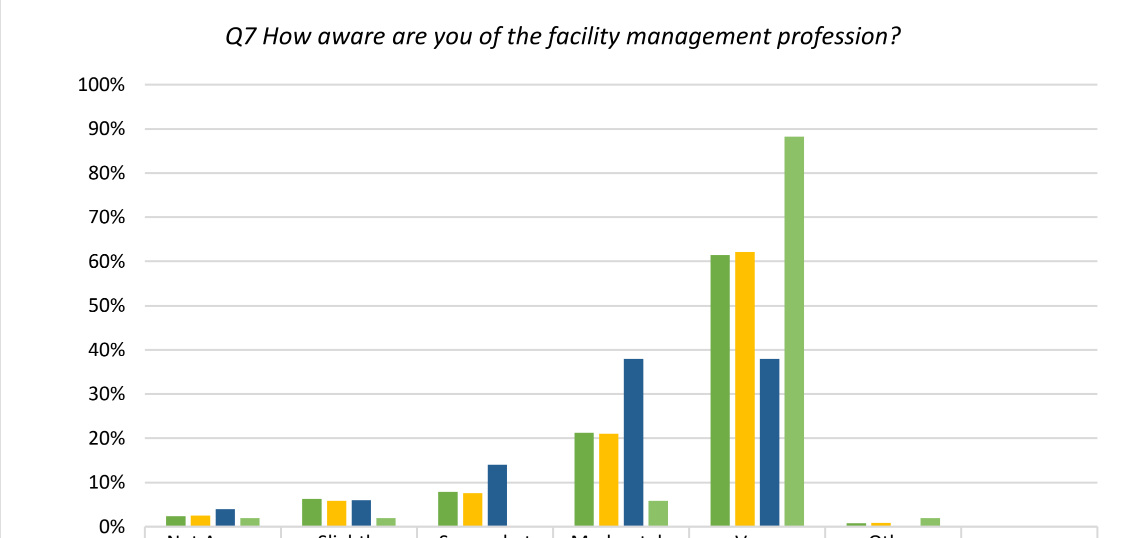


	Arch	Eng	CM	Planner	FM	NA	Other
All	14%	6%	5%	1%	16%	51%	18%
US Only	13%	5%	4%	1%	15%	53%	18%
US AE	26%	4%	0%	2%	4%	63%	7%
US FM	2%	8%	10%	0%	31%	38%	25%

Figure 6.6: Respondent professional credentials

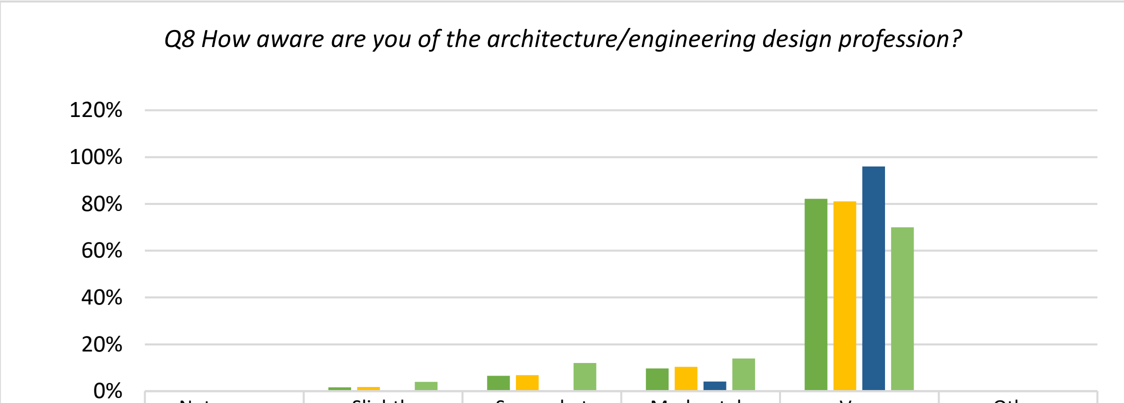
Question 7 – Question 8: Awareness of AE-design and FM professions

In Questions 7 and 8, respondents indicated a noted awareness of both the FM and AE-design professions – 85% of US AE and FM respondents were *Moderately* or *Very Aware* of the FM profession, and 90% were *Moderately* or *Very Aware* of the AE-design profession. This speaks to the respondents' ability to contribute to the study and to the study itself.



	Not Aware	Slightly	Somewhat	Moderately	Very	Other	
All	2%	6%	8%	21%	61%	1%	0
US Only	3%	6%	8%	21%	62%	1%	0
US AE	4%	6%	14%	38%	38%	0%	0
US FM	2%	2%	0%	6%	88%	2%	0

Figure 6.7: Awareness of facility management profession

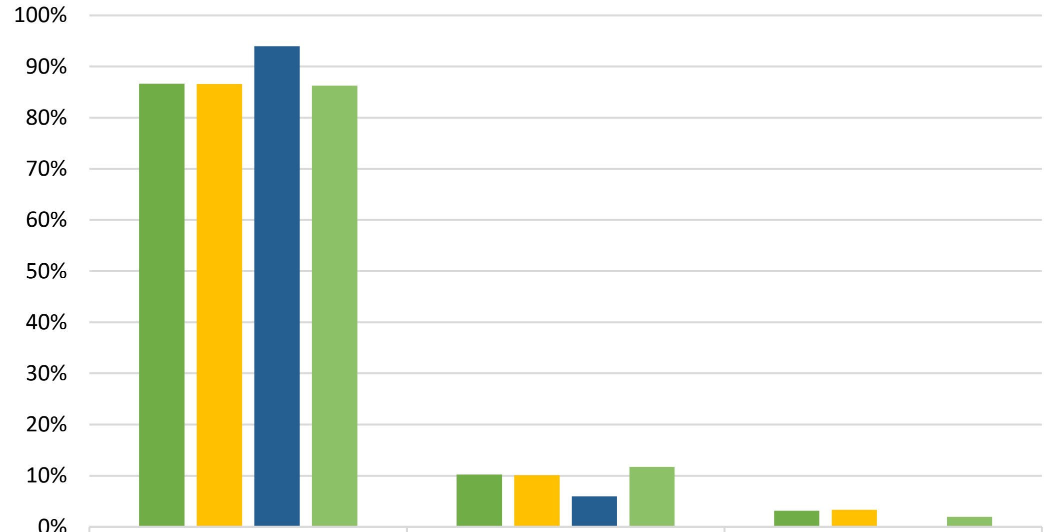


	Not aware	Slightly	Somewhat	Moderately	Very	Other
All	0%	2%	7%	10%	82%	0%
US Only	0%	2%	7%	10%	81%	0%
US AE	0%	0%	0%	4%	96%	0%
US FM	0%	4%	12%	14%	70%	0%

Figure 6.8: Awareness of architecture/engineering design profession

Question 9: Respondent new-build or major renovation involvement

Question 9 asked respondents if they had been involved in a new-build construction project or major refurbishment within the last five years. This was seen as an important question within the data set in that it directly speaks to the respondents' ability to speak on the relationship between FM and AE-design. Of the 101 US AE-FM respondents who answered this question, 91 (90%) indicated they had been involved in a new-build or significant refurbishment project within the last five years, and 9 (8.91%) indicated it had been more than five years since they were involved in such a project. Whereas one (1%) responded they had never been.

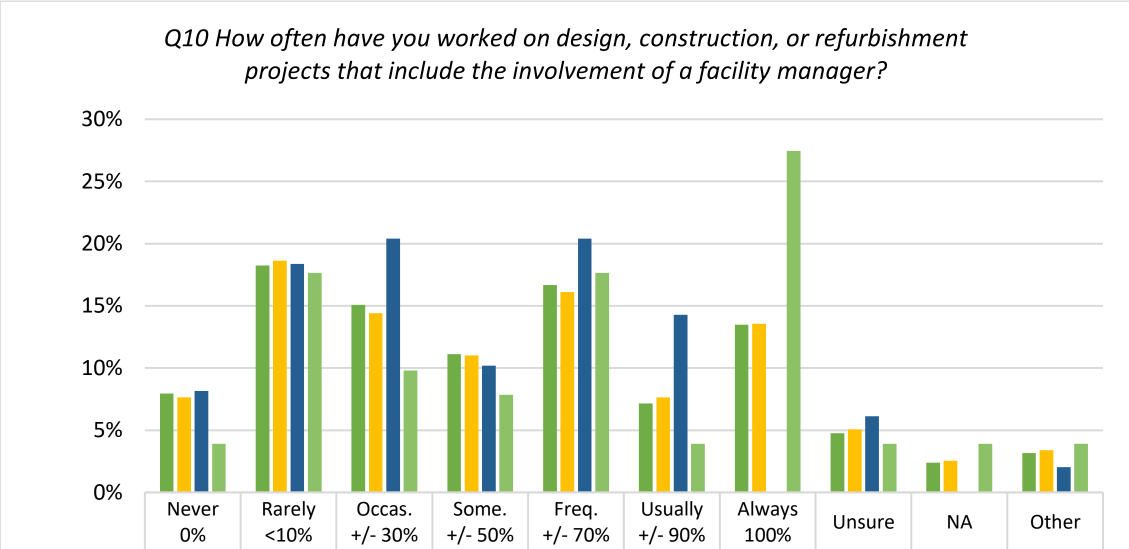


	Yes	Not w/in 5 yrs	Never
All	87%	10%	3%
US Only	87%	10%	3%
US AE	94%	6%	0%
US FM	86%	12%	2%

Figure 6.9: Experience with a new-build construction project or major renovation

Question 10: Construction project involvement of facility managers

Question 10 asked respondents to indicate how often they worked on projects that included the involvement of a facility manager. Responses indicated US AE-FM respondents worked on projects approximately 50% of the time (51%) that included the involvement of FM. When filtered to US AE only this was 45%.

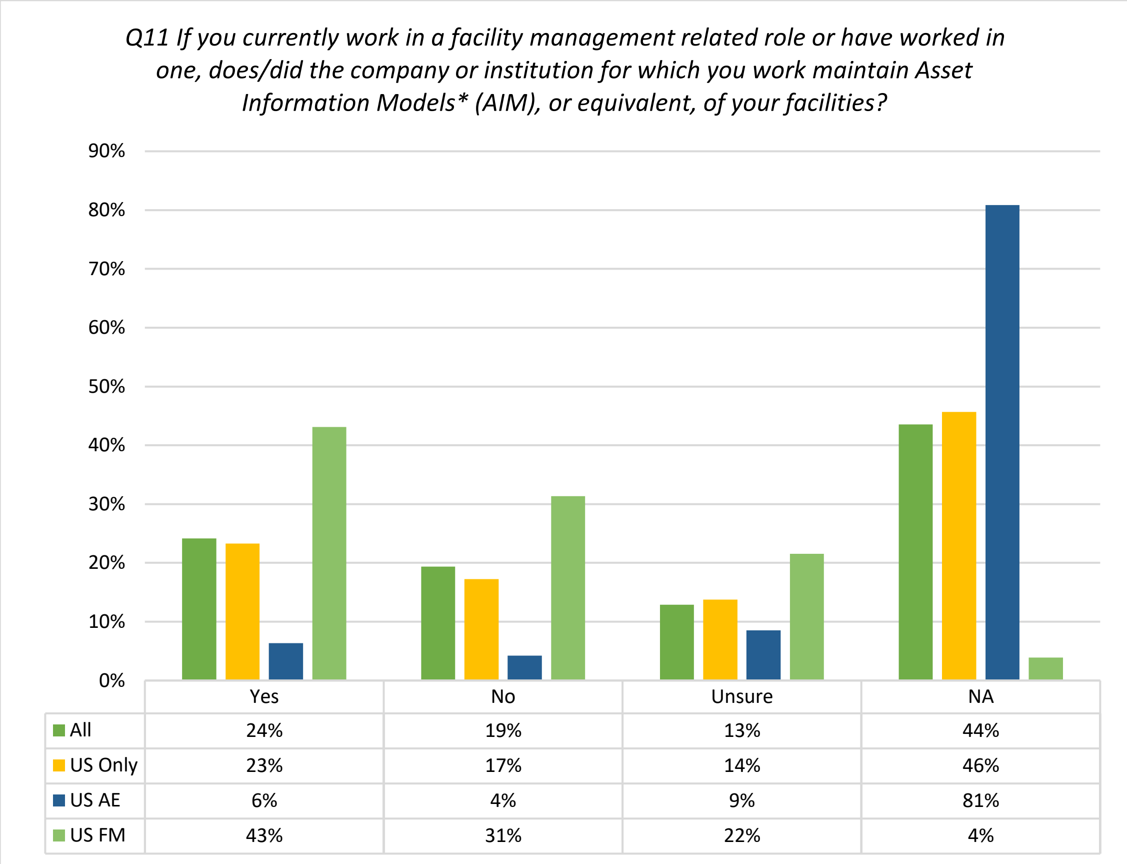


	Never 0%	Rarely <10%	Occas. +/- 30%	Some. +/- 50%	Freq. +/- 70%	Usually +/- 90%	Always 100%	Unsure	NA	Other
All	8%	18%	15%	11%	17%	7%	13%	5%	2%	3%
US Only	8%	19%	14%	11%	16%	8%	14%	5%	3%	3%
US AE	8%	18%	20%	10%	20%	14%	0%	6%	0%	2%
US FM	4%	18%	10%	8%	18%	4%	27%	4%	4%	4%

Figure 6.10: Involvement with a facility manager

Question 11: Asset Information Models (AIM)

Question 11 revealed the limited use of Asset Information Models (AIM) within the respondent pool. This question was targeted towards FM related professions due to the nature of AIMs. Out of the US AE-FM Responses, 40 responded *Not applicable*, which is expected based on the respondent breakdown in Question 3. From the remaining 61 respondents, 25 (25%) indicated they work, or had worked, for an organisation that maintains an AIM. Eighteen (18%) responded *No* and 15 (15%) responded *Unsure.* In the context of this research question, an *Unsure* response could be seen as being the same as a *No* response, as being unaware as to whether an AIM exists had the same result as not having one.



	Yes	No	Unsure	NA
All	24%	19%	13%	44%
US Only	23%	17%	14%	46%
US AE	6%	4%	9%	81%
US FM	43%	31%	22%	4%

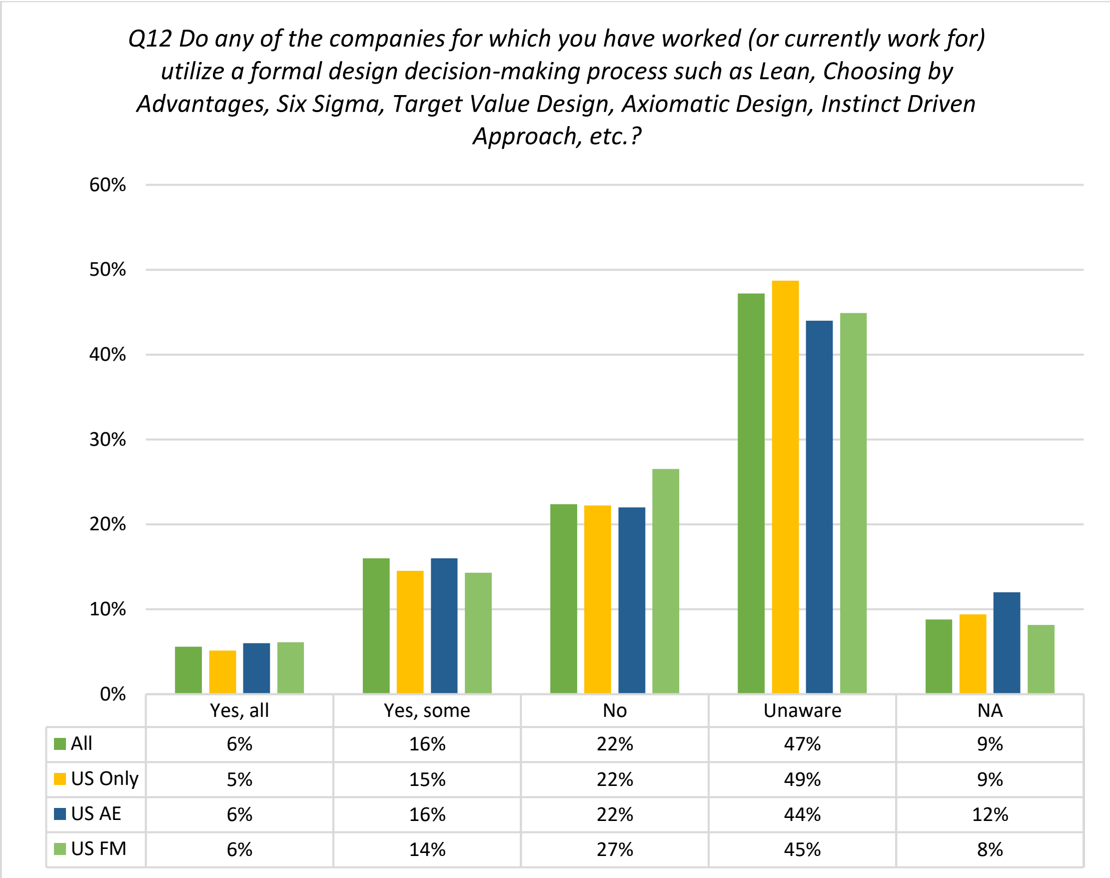
Follow up question: If you answered yes to this question, how is the model maintained? If you answered no, please briefly explain why an AIM is not maintained.

** An Asset Information Model (AIM) is a model that compiles the data and information necessary to support asset management, that is, it provides all the data and information related to, or required for the operation of an asset. An AIM can provide graphical and non-graphical data and information as well as documents and metadata. It can relate to a single asset or to a portfolio of assets.*

Figure 6.11: Use of asset information models

Questions 12 - 13: Design decision-making processes

Question 12 revealed limited use of formal design decision-making processes within the respondent pool. Only 6 (6%) of US-AE FM respondents said they used a process on all projects, and only 15 (15%) indicated they used a formal decision-making process on some projects. In addition, written comments thematically suggested a lack of formal decision-making processes and a reliance on text-based documents and notes for documenting decision-making processes.



	Yes, all	Yes, some	No	Unaware	NA
All	6%	16%	22%	47%	9%
US Only	5%	15%	22%	49%	9%
US AE	6%	16%	22%	44%	12%
US FM	6%	14%	27%	45%	8%

Follow up question: If you answered yes, what design-decision making process(s) is/was utilised? If you answered no, please briefly explain why a formal design decision-making process was/is not utilised.

Figure 6.12: Design decision-making processes

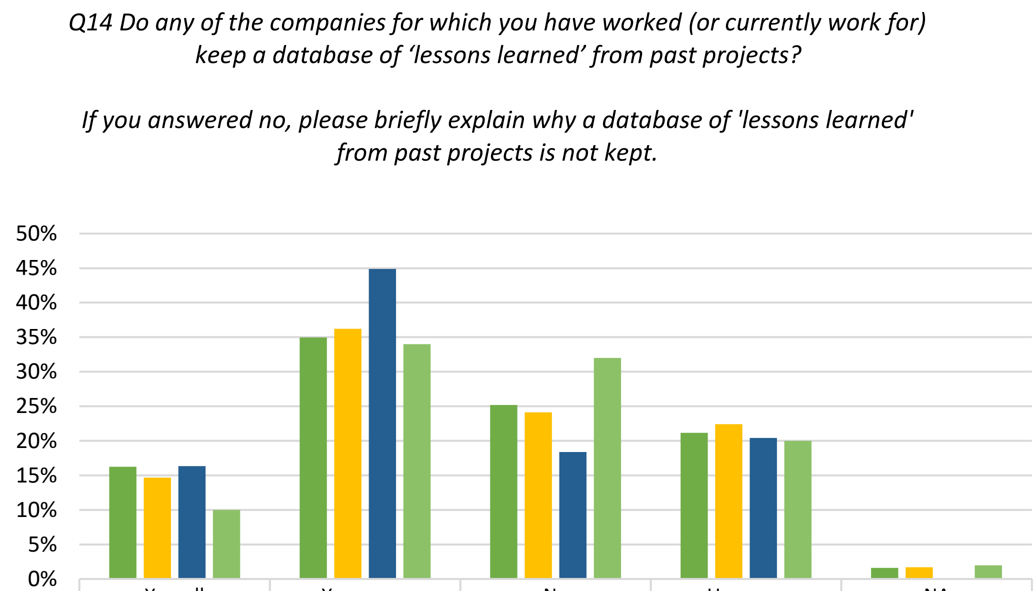
In Question 13, respondents were asked how the design decision-making processes referred to in Question 12 were documented. Fifty-seven US AE-FM respondents indicated the question was not applicable, and 44 skipped the question. Seventeen US AE-FM respondents provided written comments in response to the question. The written responses summarised below (Table 6.4) were categorised based on whether or not a formal documentation process was used for design decision-making processes.

Table 6.4: Documentation of design decision-making

Question 13: If you answered yes to the previous question, how are/were design decisions documented?	
Documentation process used	**Documentation process not used**
AE Responses	
US AE: Microsoft OneNote	US AE: Cannot answer to this regard because the projects were completed before I started at the present firm.
US AE: Meeting minutes and issues logs are how they are documented.	
US AE: Decision log tracking the initial request, decision maker/requester, decision reached/proposed, implementation status, and follow-up investigating whether it was successful.	
US AE: Written documentation of process and decisions reached.	
US AE: Lean, Integrated Design Delivery, Design Assist.	
US AE: Meeting minutes, sketching design with clients.	
US AE: Written reports and related documents.	
US AE: Written reports after Choosing-By-Advantages (CBA) work sessions.	
FM Responses	
US FM: Close and frequent coordination between me as the owner's representative and the project architect and lead engineers. Agendas, meetings, minutes, and needed follow up correspondence. Face-to-face whenever possible during programming and schematic design.	Ireland FM: CAD designs, FM, CAFM and BIM CMMS far more present doe to some horror stories here in Dublin with large American tech firms buying impressive new buildings kitting them out only to realise it doesn't align at all with how they envisage their employee culture. (Non-US)
US FM: They were first prioritised by need within the campus / building. Design decisions were made by incorporating the needs of the affected people, Facility Manager (me), and marrying that with the corporate-approved design aesthetic.	US FM: Not involved
US FM: BIM Modelling	US FM: Again, not used with or by our design firms.
US FM: MDMP	
US FM: A LCCA report would sometimes be generated. The report would be utilised to discuss with the building owner design decisions and agree upon the path forward. Major design decisions would be formalised and documented in memos. Intermediate design decisions would almost never be documented.	
US FM: Design decisions were documents in meeting minutes taken by the Architect.	
UK FM: By virtue of the pre-agreed milestones initiating client sign off (approval) - any changes post milestones would be subject to the pre-agreed change process & approval would be required ahead of implementation.	
Other	
CM US: Via meeting notes or meeting minutes and scheduling tools like ASTA Powerproject	

Question 14: Database of lessons learned from past projects

Question 14 asked respondents whether the companies for which they worked maintained a database of lessons learned. Responses suggested an almost equal split in the keeping of databases of lessons learned from past projects. Approximately 52% of US AE-FM respondents indicated they keep a database of lessons learned on at least some, or all projects. Whereas approximately 47% indicated they either do not use such a database or are not sure if they do. The latter of which has the same result as not having such a database. If respondents answered "No", there were asked to briefly explain why a database of lessons learned from past projects was not kept. Out of all respondents, 25 provided additional written comments. Representative excerpts from these written comments are provided below with the full set of comments provided in Appendix F.



	Yes, all	Yes, some	No	Unaware	NA
All	16%	35%	25%	21%	2%
US Only	15%	36%	24%	22%	2%
US AE	16%	45%	18%	20%	0%
US FM	10%	34%	32%	20%	2%

Figure 6.13: Database of "lessons learned" from past projects

A thematic analysis of the written comments, 11 out of 25 written comments suggested a lack of resources and time were barriers to maintaining a database of lessons learned from past projects. Additionally, nine responses indicated lessons learned were maintained within the minds or institutional memory of the employees; five suggested such lessons were kept in written notes or documents but were not kept in a database format; three responses suggested they thought it would be a good idea or were unsure why they did not keep such a database.

Table 6.5: Database of lessons learned, written comments

Question 14: Do any of the companies for which you have worked (or currently work for) keep a database of 'lessons learned' from past projects? (Written comments)	
Lack of resources or time	
US AE	No time to administer
US AE	It has recently been talked about starting something like this - I am not sure why they don't I assume because it takes time.
US AE	We don't make time to do it.
US AE	The database is not well maintained.
US FM	Lack of capacity to do it. It's always an intention but we move so quickly and on to the next project with little capacity.
US FM	Lack of resources and systems. Our organisation is behind on good systems for tracking results.
US FM	The amount of input required by AiM makes it undesirable to use to many employees. The amount of time that must be spent filling out reports outweighs any advantage the software might provide. Many personnel do not feel comfortable working in AiM as it is very easy to disturb work done by others.
US FM	Cost prohibitive to develop a database system, as the majority of construction projects were smaller in scale (Lifecycle system replacement).
US FM	Lack of capacity to do it. It's always an intention but we move so quickly and on to the next project with little capacity.
US FM	Lack of resources and systems. Our organisation is behind on good systems for tracking results.
US FM	It is hard to maintain and keep up with.
Institution memory or mind of the employee	
ME FM	Lessons learned were typically discussed in meetings, not logged into a database.
US AE	Lessons learned was treated more informally. There was no actual database other than our collective memories.
US AE	We have a round table series at lunch where we meet and discuss lessons learned from specific projects during different phases
US AE	It' s really what each designer is aware of and keeps an eye out.
US AE	A formal database is not kept, rather it is in the heads of those who work there. Each project manager/principal has lessons learned that they pass along as it applies to their projects.
US FM	The major component of "lessons learned" was maintained by long-term retention of the facilities project managers…
US FM	The major component of "lessons learned" was maintained by long-term retention of the facilities project managers; when I left this role in the late 1990s, we had introduced many CAD functions, but computer operating systems were generally too slow to incorporate into the actual project implementation flow.
US FM	I have never heard of doing this, I just keep a mental note of 'lessons learned'.
US FM	To clarify (and this question made me chuckle), yes, good projects and good lessons are typically put into the system. However, poor lessons and bad contractor experiences are typically stored in the mind (owner perspective/experience).
Written notes or documents	
US AE	Standards handbook was created and updated for details that are used at the firm
US FM	We don't use a database but do have Constructions Standards documents that outline our preferences and specify what will and will not be approved by the University. This includes building design, CSI spec info and product information.
US FM	Cost prohibitive to develop a database system, as the majority of construction projects were smaller in scale (Lifecycle system replacement)."
US FM	We don't use a database but do have Constructions Standards documents that outline our preferences and specify what will and will not be approved by the University. This includes building design, CSI spec info and product information.
US FM	Small company with no formal process. Individuals had experience of lessons learned but no documentation.
Good idea	
US AE	Unknown why it is not addressed and kept. It would be highly valuable to do so.
US AE	I think on a personal level you keep the lessons learned so you don't repeat them, but as a company no this is not a practice that we use right now. May talk about them, but not documented.
US AE	Unknown why it is not addressed and kept. It would be highly valuable to do so.

Question 15: Database format of lessons learned from past projects

Question 15 related to the previous question and asked respondents how lessons learned from past projects were kept. For US AE-FM respondents, *Project notes* (46%) and *Spreadsheets* (27%) represented the most used form for keeping track of lessons learned. Respondents who selected *other* were asked to explain. Eight meaningful written comments were provided which supported these numbers (Table 6.6). One theme arose from these written comments – lessons learned from past projects were primarily kept in text-based documents such as Microsoft Word or emails. Representative excerpts are provided below with the full set provided in Appendix F.

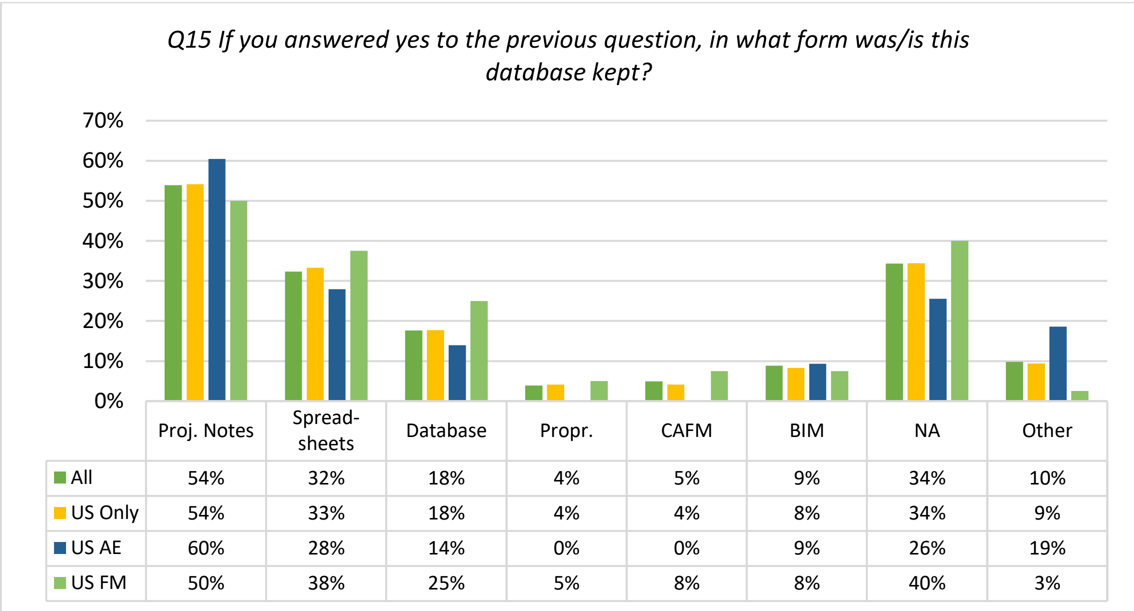


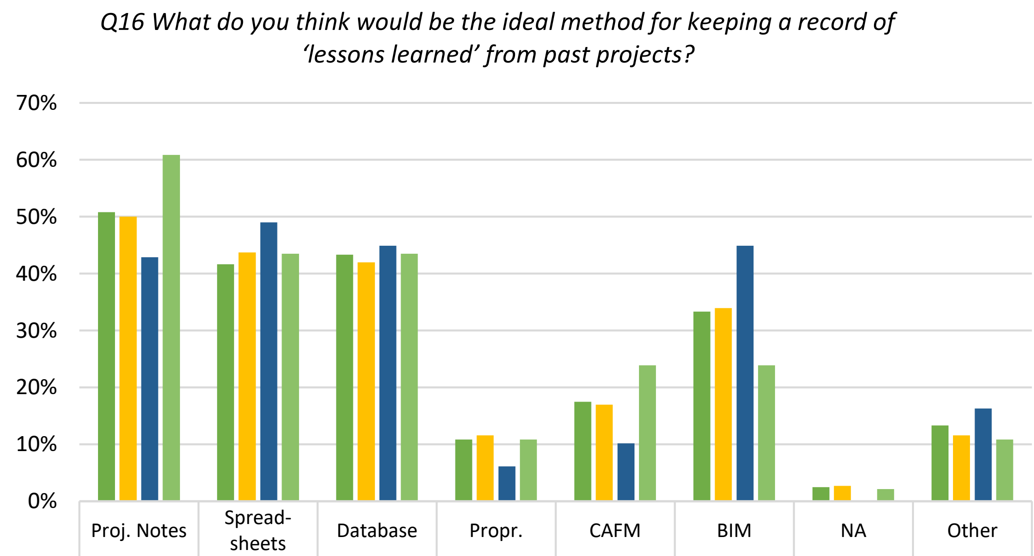
Figure 6.14: Methods for maintaining a "lessons learned" database

Table 6.6: Ideal methods for maintaining a "lessons learned" database

Question 15: If you answered yes to the previous question, in what form was/is this database kept? (Written comments)		
Database		
US AE	Database	Internal internet/database
Text Based Notes		
US FM	Text notes	This is a Microsoft word document with PDF attachments.
US AE	Text notes	Point of Clarity - Again, I work for smaller groups/companies typically, so the President of the company keep all notes of any problems from past projects, but no formally documented/catalogued database. Typically, just a file folder with handwritten notes clasped in alongside a myriad of other project related notes.
US AE	Text notes	Handbook
US AE	Text notes	Written as comments into in-house specification files.
US AE	Text notes	Notes written into spec documents and a running list in a Word document shared on office server.
Verbally Communicated		
US AE	Verbal	Cross team project meetings to share lessons learned and associated presentation material.
US AE	Verbal	Verbal

Question 16: Ideal method for keeping lessons learned from past projects

Question 16 asked respondents what they thought would be the ideal method for keeping track of lessons learned from past projects. Respondents were asked to consider this question regardless of whether they kept track of such lessons themselves. *Project notes* (49%), *Spreadsheets* (44%), and *Generic database (*42%) were almost equally identified by US AE-FM respondents as the ideal method for keeping track of lessons learned. *BIM related software* (33.33%) was the next most selected option.



	Proj. Notes	Spread-sheets	Database	Propr.	CAFM	BIM	NA	Other
All	51%	42%	43%	11%	18%	33%	3%	13%
US Only	50%	44%	42%	12%	17%	34%	3%	12%
US AE	43%	49%	45%	6%	10%	45%	0%	16%
US FM	61%	43%	43%	11%	24%	24%	2%	11%

Figure 6.15: Ideal method for keeping a record of lessons learned

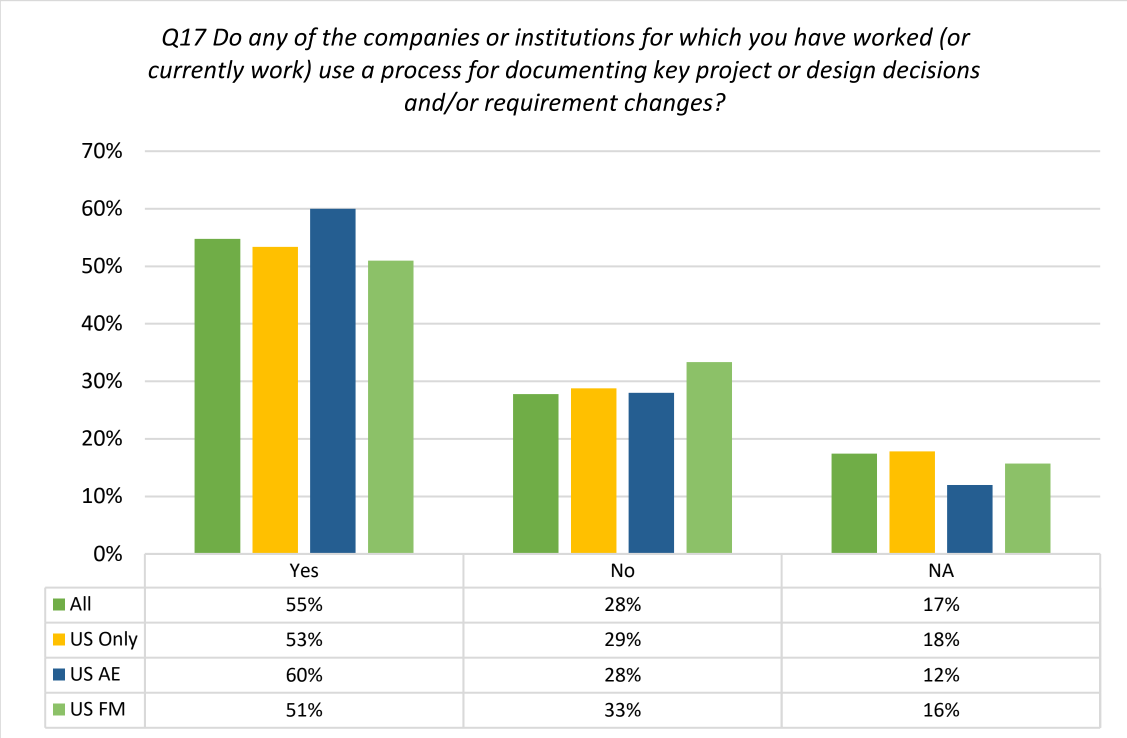
Respondents who selected *Other* were asked to explain. Fifteen respondents provided written comments with representative examples provided below. Thematically, the written comments suggested any system for tracking lessons learned must be easily managed and updated. Furthermore, it would need to fit within existing workflows. (A full list of written comments can be found in Appendix F.)

Table 6.7: Ideal method for keeping records of 'lessons learned' from past projects

Q16 What do you think would be the ideal method for keeping a record of 'lessons learned' from past projects? (Written comments)		
Checklist		
US AE	Checklist	An easily referenced and frequently updated checklist, ongoing changes to template drawings and details
Database		
US FM	Database	I work in public K-12 arena and our industry would benefit from an archive that other projects could review as to avoid similar mistakes
US FM	Database	Some sort of searchable data base. I am not a fan of *home-grown* solutions as they are difficult to maintain over the long term.
General Software System		
US AE	Software	Spec related software
US AE	Software	Whatever system is easy to use and navigate. I've been involved in several new software *rollouts* that no one really adopted.
Text Based Notes		
US FM	Text notes	I do not know enough to recommend a good way to do it besides project notes
US FM	Text Notes	Realistically, with our we are organisationally setup, it's difficult for us on the owner side to manage this formally. We lean more on our design and construction partners to update and revisit lessons learned as we move into new projects (via notes and meeting *kick-off* meetings).
US FM	Text Notes	Our standards are a live document and get updated as issues happen in real time.
Visual Communication		
US AE	Visual	Office wide presentation
US AE	Visual	Perhaps somewhat more of an interactive meeting / presentation to go over and explain with questions and answers.
Not Specified		
US AE	NA	Depends on the tools and systems used in the organisation.
US AE	NA	Any formal database requires someone to review the information and then decide if a particular lesson might apply to a new and unique *project*. Seems unlikely to be effective.

Question 17: Documenting key decisions and requirement changes

Questions 17 related to the documentation of crucial project decisions and requirement changes made over the course of the project. Question 17 suggested only 56% of US AE-FM respondents used a process to track design decisions and/or project requirement changes. Additionally, respondents were asked to comment in writing what type of process they used if they used one, or why they did not document design decisions or project requirement changes if they did not. Out of the total 126 responses to this question, 62 provided written comments with 50 comments coming from US AE-FM respondents. A thematic analysis of these written comments suggested a reliance on text-based documents and notes when critical decisions or requirement changes were tracked. OneNote, Blue Beam, PlanMetrics, Hubspot, Procore, Newforma, and general project notes and spreadsheets were mentioned specifically as software packages or processes used to document related changes and decisions.



Follow up question: If you answered yes, what was/is their process for documenting such decisions or changes? If you answered no, please briefly explain why a process for documenting such project decisions or changes is not utilised.

Figure 6.16: Process for documenting project decisions and requirement changes

Question 17: Process Used to Document Project Decisions and Requirement Changes		
Database		
USAE	Database, Software	Internal/proprietary change log database tracking requester, description, rationale, impacts to other groups, and FF&E costs.
USFM	Database, Text notes	Plans and notes are sent to a centralised team that maintains documents and posts them to a database available for review.
General Software System		
USAE	Software	Newforma.
USAE	Software	Procore or blue beam.
USFM	Software	Cost prohibitive to develop an IT system, as the majority of construction projects were smaller in scale (Lifecycle system replacement).
USFM	Software	e-builder.
USFM	Software	Proprietary system for each individual project.
USFM	Software, Database, Text Notes, Spreadsheets	Projnet, Access, Word Doc's, Excel.
USAE	Software, Spreadsheets	Change order Logs, spreadsheets, formalised lessons learned process, and reports generated by maintenance management software.
USAE	Spreadsheets	Spreadsheets.
Text Based Notes		
USAE	Text notes	Notes in project file.
USAE	Text notes	We develop an Owners Project Requirements document and then a Basis of Design document.
USAE	Text notes	Email, Letters, other "written" forms of communication.
USAE	Text notes	We really should be doing this; however, we are very busy and the least we do is have the client either approve the change through email and saving that email in project folders. This is not a good process we should have a change order completed and signed by the client.
USAE	Text notes	Mostly, project notes/minutes of O/A meetings.
USAE	Text notes	We keep a OneNote file that is updated frequently so there is always something to reference.
USAE	Text notes	ASIs, PCOs, office wide email.
USAE	Text notes	Meeting minutes.
USAE	Text notes	Keeping project notes on all projects.
USAE	Text notes	Email summaries.
USAE	Text notes	.pdf / text documentation created by design team and filed within appropriate job folders on company server.

USAE	Text notes	Email.
USAE	Text notes	through notes or AIA documents and final through documents in the model or drawings.
USAE	Text notes	An informal system of meeting minutes which may include design direction is kept, but nothing is maintained throughout the lifetime of the project.
USFM	Text notes	This is currently captured via meeting minutes and drawing mark-ups.
USFM	Text notes	What - When - Who, in that order, so all management participants know the decision process prior to the start of construction. It often was done using 5" x 8" programming cards organised on a 20-foot long tackable wall. It provided the sequence of decision making and allowed the project team to determine when to ask for approvals (and funds) and reduced unanticipated snafus because we had some control over who made the decisions.
USFM	Text notes	For large/complex projects a Basis of Design document would be utilised to document major design decisions. However, often times the BOD document would not be updated, as the A/E team was under extreme pressure to deliver the construction documents within shorter timeframes.
USFM	Text notes	Meeting minutes.
USFM	Text notes	Information from job meetings, project notes and discussions with architects, engineers, and Owner Project Manager/Clerk of Works.
USFM	Text notes	We don't have a formal process. Most Project Managers have a design, finance or law background so know when to elevate decision making (mostly around financial and cost related matters). That said, nothing is formally documented other than confirmation via email.
USFM	Text notes	Building Committee notes and change orders handle changes in the field.
USFM	Text notes	Construction meeting notes that were transferred to spreadsheet and MS Word application.
USFM	Text notes	Building committees meeting minutes.
USFM	Text notes	Meeting minutes reviewed and approved by the owner for any major project decisions that would impact scope or change requiring additional funding.
USFM	Text notes	Usually meeting minutes.
USFM	Text notes	I could write a book on the process, but yes, to sum up this response, all information from initial concept to turnover of construction is/will-be documented in a shared computer drive (reason for construction, justification, preliminary sketches/ideas, drawings, budgets, SOW, bidding, construction, commissioning, etc.).
USFM	Text notes	Through meeting minutes taken by the Architect.
USFM	Text notes	We use change orders to document changes.
USFM	Text notes	Yes, but it is not always consistent depending on which employee was responsible for documenting these changes. Workers are expected to scan in and store all pertinent information on a shared network drive, but it is often overlooked. Any information that is relayed through email is lost very often as many employees fail to move these documents to the drive.
USAE	Text notes, Checklists, Spreadsheet, Software	Depending on which phase we are within a given project, RFI, ASI, etc are used. We also use internal checklist. Each design phase has its own checklist. When a design decision is made it should go in that checklist. The checklist is within excel and an external program called teamwork.
USAE	Text notes, Drawings	Process varies by project and project team but usually includes sketches, graphics, budgets, and value engineering lists that attempt to catalogue major decisions or changes.
USAE	Text notes, Drawings	Every revision is kept track of, drawings are filed in dated folders, with at least of a brief explanation of the changes as we progress through the projects.
USFM	Text notes, Drawings, Software	The Facilities Engineering department provides document reviews, annotates the required and recommended changes using spreadsheets and notes on drawings. Most drawings are marked up using BlueBeam Revu or similar PDF markup programs.
USFM	Text notes, Forms	Meeting notes (standard forms) ...flowed from Architect to contractors depending on project phases.
USAE	Text notes, Spreadsheets	Meeting minutes or issues log / VE log spreadsheets.

Figure 6.17: Process used to document project decisions and requirement changes

Question 18: Documenting key decisions and requirement changes

Question 18 asked respondents what they thought would be the ideal method for tracking design decisions and project requirement changes. Respondents could select more than one option and were asked to consider this question regardless of whether they kept track of such lessons themselves. *Project notes* (63%) was the most widely identified option. *Spreadsheets* (40%), *Generic database* (31%), and *BIM related software* (35%) were identified almost equally by US AE-FM respondents as the second tier for an ideal method for keeping track of design decisions or project requirement changes. Respondents who answered *Other* were asked to specify (see Appendix F for a full list of written comments).

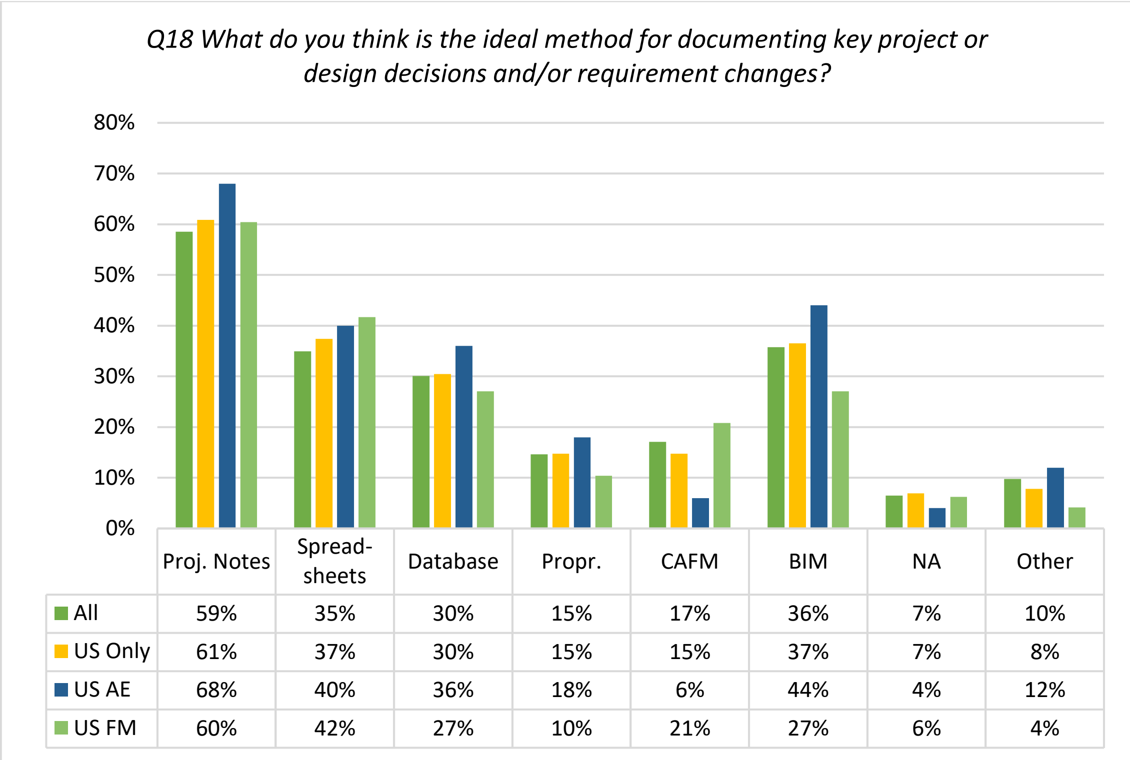


Figure 6.18: Ideal method for documenting decisions and requirement changes

Table 6.8: Ideal method for documenting decisions and requirement changes

Question 18: Ideal method for documenting decisions and requirement changes		
Text Based Notes		
US AE	Text notes	A document that the owner can provide written confirmation or approval.
US AE	Text Notes	Project emails between design principal, owner, relevant consultants.
Training		
US AE	Training	Building on or developing, training, and fully implemented systems to be used in an organisation.
Visual		
US AE	Visual	Office wide presentation.
Not Specified		
US AE	NA	What makes sense varies by client and project type/size.
US FM	NA	Have an assistant!
US FM	NA	I don't know, but someone could make a lot of money if they figured this out!

Question 19: FM data most helpful to share with AE-design

Question 19 asked what information respondents thought would be most helpful to share from FM to AE-design teams. Responses were provided in writing from 78 respondents in total and 64 US AE-FM respondents (Appendix F). Representative written comments from US AE-FM are provided in Table 6.9. A thematic analysis of these responses found the following themes:

1. Information related to standard FM/O procedures to be performed once the facility is in operation;
2. Space and occupancy use of existing or similar facilities;
3. Historic records associated with maintenance and utility costs;
4. The knowledge and skill set of FM/O staff; and
5. Internal facility specifications for materials, equipment, et cetera.

Table 6.9: Helpful FM data or information to AE-design teams, written comments

Question 19: What FM/O related data or information do you believe would be most helpful to provide from FM to A/E design teams?	
FM/O procedures	
US CM	Preventative / routine maintenance tasks that are needed to be performed safely. (i.e., maintenance staff working on RTUs, but not having parapets designed at the minimum handrail height by OSHA's standards)
US CM	Location of HVAC units located above ACTs. For example, units are sometimes located at heights or in areas that are difficult to manoeuvre during the lifetime of the building to replace filters or work on.
US FM	Materials selection is another issue we have seen. We spec beautiful, green materials that aren't maintained well because the Ops team might use bleach on everything and it's too hard to switch out for just one floor. So, understanding the operations side is helpful during the design phase and vice versa.
US AE	How is the facility used on a daily basis, what aspects of the daily operations do they struggle to accomplish, what processes/et cetera. are worth holding onto, what is the decision-making process.
Space or occupancy use	
US FM	How the space is actually used compared to how engineers/designers think the space should be used
US FM	Flow of the building/space layout from an operations perspective. A recent example: architects designed a bike room with no access from the exterior for safety concerns. Ops team pointed out location of bike room relative to building lobby entrance and what the means on a rainy day to traipse a wet bike across an entire lobby. Similar situation for the location of a trash compactor room relative to the operations of trash collection.
US AE	How the facility is used. What items are "wrong" in the current facility as well as what works in the facility.
Historical records and costs	
US FM	Data concerning occupancy and use of space, as well as utility costs, prove to be extremely useful.
Knowledge and skills of FM staff	
US AE	Maintenance capabilities and experiences. What materials/patterns/techniques last a long time without maintenance.
US FM	Maintenance staff size and skills to be able to tailor design to the ability to maintain the bldg, grounds and eqpt.
US AE	Current facility maintenance software packages, how they are used and hopes for the updated/new facility, current and proposed staffing, and experience to ensure new facility can be operated with current or proposed staff, discussion of current facilities and issues to be improved, Desired level of technology and variation in materials to simplify operation, cleaning, and maintenance.
Internal specifications	
US AE	A detailed, up-to-date list of all finish specifications, equipment specifications - either embedded in a project manual or utilising BIM to house this information.
US AE	Materials used with detailed information about the products. Best practice for maintenance.
Other	
US FM	Build in maintenance into design. Not just something "pretty" but design it to last and be maintained as well.
US FM	That the Facilities Manager is just as valuable to the team in order to maintain the facilities after many years. The Arch and Eng are gone after the project, but the FM has to maintain the building and property for many years.

Question 20: Usefulness of FM data for use by AE-design

Question 20 asked respondents to evaluate what information would be most helpful to provide to design teams from FM/O. This question was not open-ended, where Question 19 was. Question 20 provided a list of information categories which the respondents were asked to individually evaluate.

Table 6.10 shows responses for the filtered US AE-FM response pool. This table was limited to these responses to be able to make a direct comparison between the two groups. In the table below, statistically significant variance between the two groups is highlighted in orange (see Section 4.5.4).

Table 6.10: Useful FM data to share with AE-design teams

Question 20: How useful would the following facility management/operations data categories be to A/E design teams during the design process? (Please provide additional answers as needed)										
	Extremely useful		**Very useful**		**Somewhat useful**		**Not so useful**		**Not at all useful**	
	AE	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**
Janitorial unit costs	0%	24%	14%	29%	37%	31%	26%	14%	23%	2%
Janitorial cleaning frequency	5%	31%	33%	36%	44%	24%	7%	7%	12%	2%
Maintenance unit costs - corrective	10%	40%	29%	33%	48%	24%	7%	2%	7%	0%
Maintenance unit costs - scheduled	7%	40%	35%	44%	44%	14%	7%	2%	7%	0%
Maintenance unit costs - exceptional	9%	29%	19%	41%	51%	24%	14%	5%	7%	0%
Occupancy and use (space utilisation)	67%	70%	28%	26%	5%	5%	0%	0%	0%	0%
Operational unit costs	14%	56%	44%	33%	37%	9%	0%	2%	5%	0%
Facility or employee productivity	26%	33%	26%	40%	33%	19%	9%	7%	7%	2%
Staffing or employee labour unit costs	9%	24%	19%	38%	37%	26%	26%	10%	9%	2%
Employee or customer/user satisfaction	44%	40%	37%	33%	16%	21%	2%	7%	0%	0%
Utility or energy consumption and/or unit costs	40%	70%	47%	28%	12%	2%	2%	0%	0%	0%

The top three categories identified as being *Extremely useful* are shown below, with related numbers for all respondents and those filtered by US AE or FM respondents (Table 6.11).

Table 6.11: Top three categories of data helpful to share from FM to AE-design

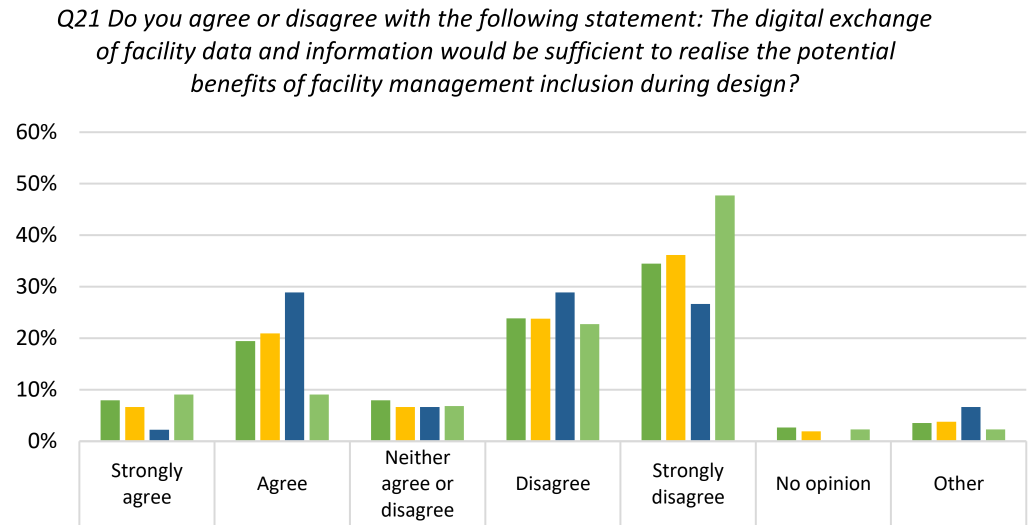
Question 20: Top three categories *Extremely useful* categories from all respondents			
Category	**All Respondents**	**AE Combined**	**FM Combined**
Occupancy and use (space utilisation)	67.68%	70.00%	73.17%
Utility or energy consumption and/or unit costs	56.57%	42.50%	65.85%
Employee or customer/user satisfaction	41.41%	47.50%	39.02%
Top three categories *Extremely useful* categories from FM respondents (Note: The top three categories for AE-combined matches the table above and are not provided a second time)			
Category	**All Respondents Equivalent**	**AE Combined Equivalent**	**FM Combined**
Occupancy and use (space utilisation)	67.68%	70.00%	73.17%
Utility or energy consumption and/or unit costs	56.57%	42.50%	65.85%
Operational unit costs	34.34%	17.50%	53.66%

The question was answered by 106 respondents, and seven provided additional written comments. Meaningful written comments are provided below. Three additional respondents provided written answers indicating the question did not apply to them.

> **US-AE:** All these are good but are only somewhat useful to an architect and the client. In our line of work, cost of a project is what drives the deliverables. Yes, these areas may be great to consider, but the overall building and making for the client gets what they desire is more important. (Especially in a mixed-use affordable housing project).
>
> **US-FM:** I am a facility manager so all of those items I feel are important.
>
> **US-FM:** Spectrum of performance vs. cost and appearance. Schools shouldn't have expensive and hard to maintain elements to deal with after the occupancy period begins.
>
> **UK-FM:** There are too many categories to list - a complete interface with building services is critical.

Question 21: Digital exchange of information

Question 21 asked if respondents thought the digital exchange of information was sufficient to realise the potential benefits of FM/O involvement in the AE-design process. This question was asked to determine if respondents thought face-to-face interaction between AE and FM was necessary or if a digital transfer would be sufficient. Within the US AE-FM responses a majority (56%) of respondents *disagreed* or *strongly disagreed* that the digital exchange of information would be sufficient. Respondents who indicated *Other* were asked to explain.



	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	No opinion	Other
All	8%	19%	8%	24%	35%	3%	4%
US Only	7%	21%	7%	24%	36%	2%	4%
US AE	2%	29%	7%	29%	27%	0%	7%
US FM	9%	9%	7%	23%	48%	2%	2%

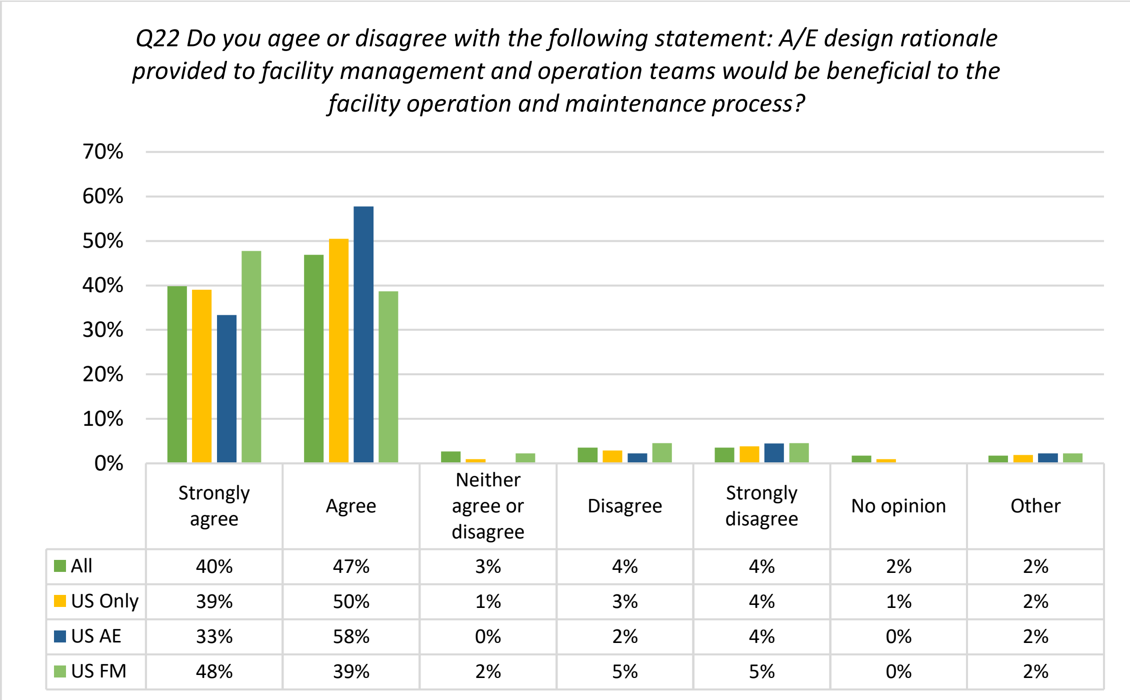
Figure 6.19: Digital exchange of facility data and information

Of the 113 respondents, four provided written comments which are provided below.

> **US-FM:** There needs to be face and face with the building designers from a facility manager perspective.
>
> **US-AE:** Digital exchanges would be extremely beneficial but may require some explanation of the data once received by designers. Interpreting building management data could be cumbersome and difficult if not utilised frequently.
>
> **US-AE:** Changing technology will also require training infrastructure, funding of that infrastructure, and ongoing professional development to keep the facilities operating as intended.
>
> **US-AE:** Agree - but only so far as being contingent on the semantic use of REALISING the potential benefits, and not to go so far as to utilise them.

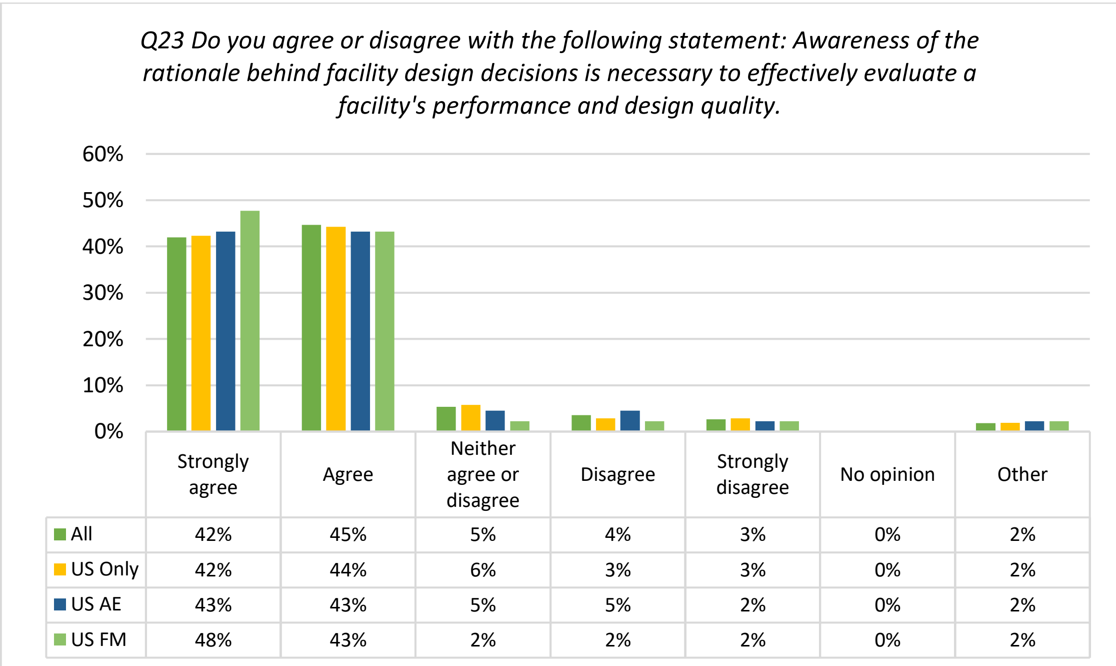
Question 22 – Question 23: AE-design decision rationale shared with FM/O

Questions 22 and 23 asked respondents to consider the value of AE decision rationale being provided from AE-design to FM/O. Responses to both questions suggested *agreement* or *strong agreement* to both questions. Respondents who indicated *Other* were asked to explain. Written responses to both questions are provided below.



	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	No opinion	Other
All	40%	47%	3%	4%	4%	2%	2%
US Only	39%	50%	1%	3%	4%	1%	2%
US AE	33%	58%	0%	2%	4%	0%	2%
US FM	48%	39%	2%	5%	5%	0%	2%

Figure 6.20: Design rationale provided to FM/O teams



	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	No opinion	Other
All	42%	45%	5%	4%	3%	0%	2%
US Only	42%	44%	6%	3%	3%	0%	2%
US AE	43%	43%	5%	5%	2%	0%	2%
US FM	48%	43%	2%	2%	2%	0%	2%

Figure 6.21: Awareness of the rationale behind facility design decisions

Table 6.12: Question 22 and Question 23, written comments

Question 22 and 23: Written comments
Q22
US AE: I would agree only if Facility Management and operation teams had an opportunity to provide input early on and throughout the design process.
US FM: Whenever I built a project without the involvement of the future occupants, the FM ops personnel, the building was an orphan, maintenance was poor. There is one thing worse than having an insistent owner, that's having none at all.
Q23
US AE: The initial stage. (Feasibility)
US FM: If it were done, I would agree.

Question 24: Project stages to share data from FM to AE-design

Question 24 asked respondents to evaluate the most useful project phase for data and information to be transferred from FM to AE-design. Respondents were asked to select all results that applied and could therefore select multiple results. Responses suggested early involvement was viewed as more valuable than later involvement, with an ongoing need for some continued involvement. Seven respondents provided written responses which are provided below and are categorised by when they indicated it would be beneficial to share data from FM to AE-design. Respondents who indicated *Other* were asked to explain.

Post Occupancy:

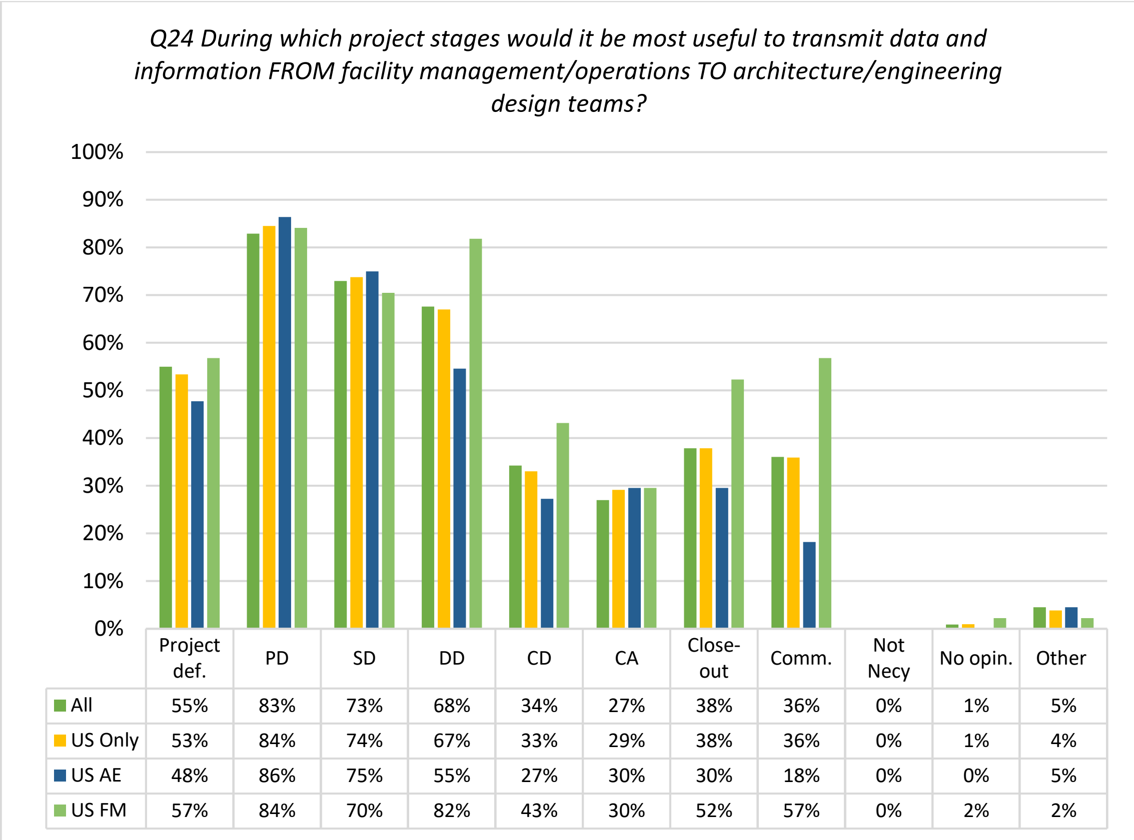
US-FM: Post-Occupancy

US-AE: One year after occupancy

Early Involvement:

US-AE: It is more appropriate and likely to yield positive outcomes if facility management/operations are included in the design process through all stages of project definition through the completion of project commissioning.

US-Other: DD and CD phases are too late to incorporate FM information because at that time project feasibility has been determined along with project budget and FM information at that point could make or break a project from moving forward.



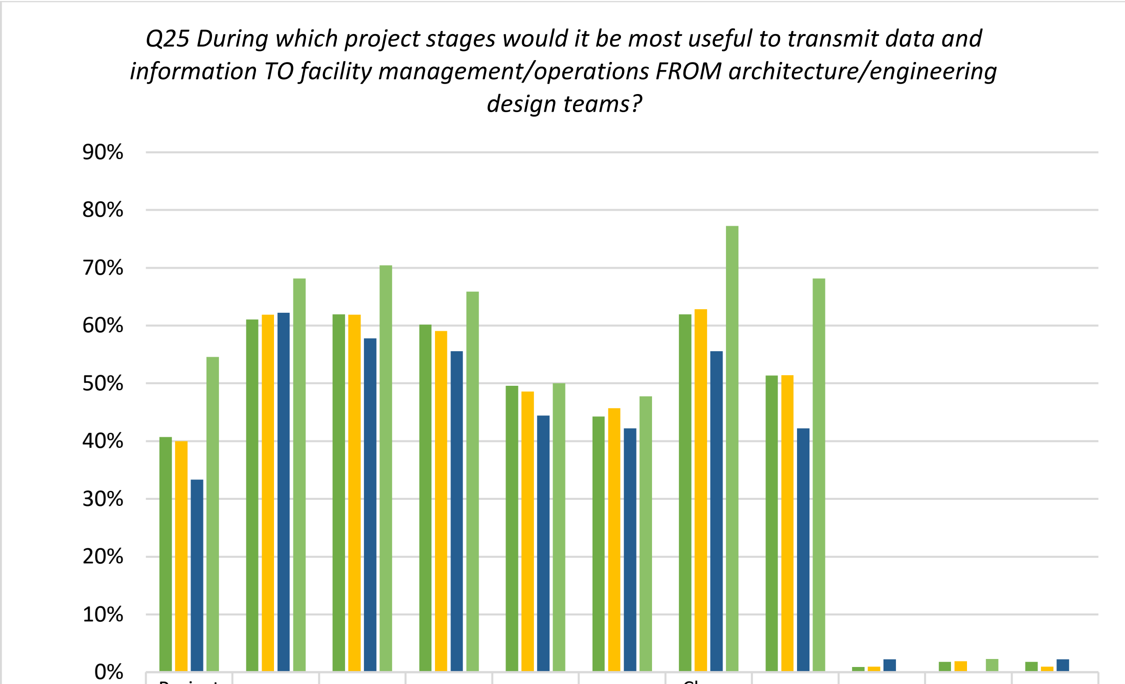
	Project def.	PD	SD	DD	CD	CA	Close-out	Comm.	Not Necy	No opin.	Other
All	55%	83%	73%	68%	34%	27%	38%	36%	0%	1%	5%
US Only	53%	84%	74%	67%	33%	29%	38%	36%	0%	1%	4%
US AE	48%	86%	75%	55%	27%	30%	30%	18%	0%	0%	5%
US FM	57%	84%	70%	82%	43%	30%	52%	57%	0%	2%	2%

Figure 6.22: Useful project stages to transmit data and information – FM to AE

Question 25: Project stages to share data from AE-design to FM

Question 25 asked respondents to evaluate the most useful project phase for data and information to be shared from AE-design to FM. Respondents were asked to select all results that applied and could therefore select multiple results. Responses suggested an ongoing need for the transfer of information from AE to FM during all project phases. Respondents who indicated *Other* were asked to explain. Written responses are provided below:

> **US-AE:** It is more appropriate and likely to yield positive outcomes if A/E professional include facility management/operations in the design process through all stages of project definition charettes through the completion of training and project commissioning.
>
> **West Asia-FM**: Depends on the project & program, I would suggest.



	Project def.	PD	SD	DD	CD	CA	Close-out	Comm.	Not Necy	No opin.	Other
All	41%	61%	62%	60%	50%	44%	62%	51%	1%	2%	2%
US Only	40%	62%	62%	59%	49%	46%	63%	51%	1%	2%	1%
US AE	33%	62%	58%	56%	44%	42%	56%	42%	2%	0%	2%
US FM	55%	68%	70%	66%	50%	48%	77%	68%	0%	2%	0%

Figure 6.23: Useful project stages to transmit data and information – AE to FM

Question 26 – Question 27: Familiarity with various building classification systems

Questions 26 and 27 asked respondents to indicate their familiarity and the perceived value of various building classification systems.

Table 6.13 shows responses for the filtered US AE-FM response pools for Question 26. This table was limited to these responses to be able to make a comparison between the two groups. In the table below, statistically significant variance between the two groups were highlighted in orange.

Table 6.14 shows responses for the filtered US AE-FM response pools for Question 27. This table was limited to these responses to be able to make a direct comparison between the two groups. In the table below, statistically significant variance between the two groups was highlighted in orange (see Section 4.5.4).

Table 6.13: Familiarity with building systems classification systems

Question 26: How familiar are you with the following building systems classification systems?										
	Not at all familiar		Slightly familiar		Somewhat familiar		Moderately familiar		Very familiar	
	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM
OmniClass (OCCS)	81%	88%	12%	3%	5%	5%	0%	3%	2%	3%
MasterFormat	**27%**	**59%**	18%	12%	**20%**	**0%**	18%	17%	16%	12%
UniFormat	70%	73%	15%	8%	8%	5%	0%	8%	8%	8%
Uniclass	85%	85%	12%	10%	2%	0%	0%	3%	0%	3%
IFC	70%	80%	14%	10%	14%	5%	2%	3%	0%	3%
COBie	81%	71%	9%	20%	7%	5%	2%	5%	0%	0%
CI/SfB	95%	90%	5%	7%	0%	0%	0%	2%	0%	0%
CAWS	95%	88%	5%	10%	0%	0%	0%	0%	0%	2%
NRM (New Rules of Measurement)	95%	98%	5%	2%	0%	0%	0%	0%	0%	0%
A Proprietary system	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 6.14: Classification systems regularly used

Question 27: Which of the following building systems classification systems do you regularly use (or have regularly used)?																		
	Never (0%)		Rarely (Less than 10%)		Occasionally (About 30%)		Sometimes (About 50%)		Frequently (About 70%)		Usually (About 90%)		Always (100%)		I do not know		Not applicable	
	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM	AE	FM
Omni-Class	81%	79%	10%	5%	0%	0%	0%	0%	0%	5%	0%	0%	2%	0%	7%	8%	0%	3%
Master-Format	35%	59%	16%	5%	5%	0%	5%	0%	5%	0%	7%	10%	19%	15%	9%	8%	0%	3%
Uni-Format	71%	68%	12%	8%	0%	3%	2%	0%	2%	3%	2%	5%	2%	3%	7%	8%	0%	3%
Uni-class	86%	84%	7%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	7%	8%	0%	3%
IFC	81%	70%	7%	8%	0%	5%	2%	3%	0%	3%	0%	0%	0%	0%	10%	8%	0%	3%
COBie	88%	76%	5%	8%	0%	3%	0%	3%	0%	0%	0%	0%	0%	0%	7%	8%	0%	3%
CI/SfB	88%	82%	5%	5%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	7%	8%	0%	3%
CAWS	88%	82%	5%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	8%	0%	3%
NRM	88%	84%	5%	3%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	7%	8%	0%	3%
Prop.	76%	61%	5%	3%	3%	3%	0%	12%	3%	3%	0%	0%	3%	0%	11%	12%	0%	6%
Other	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Question 28: Effectiveness of building classification systems to transmit data

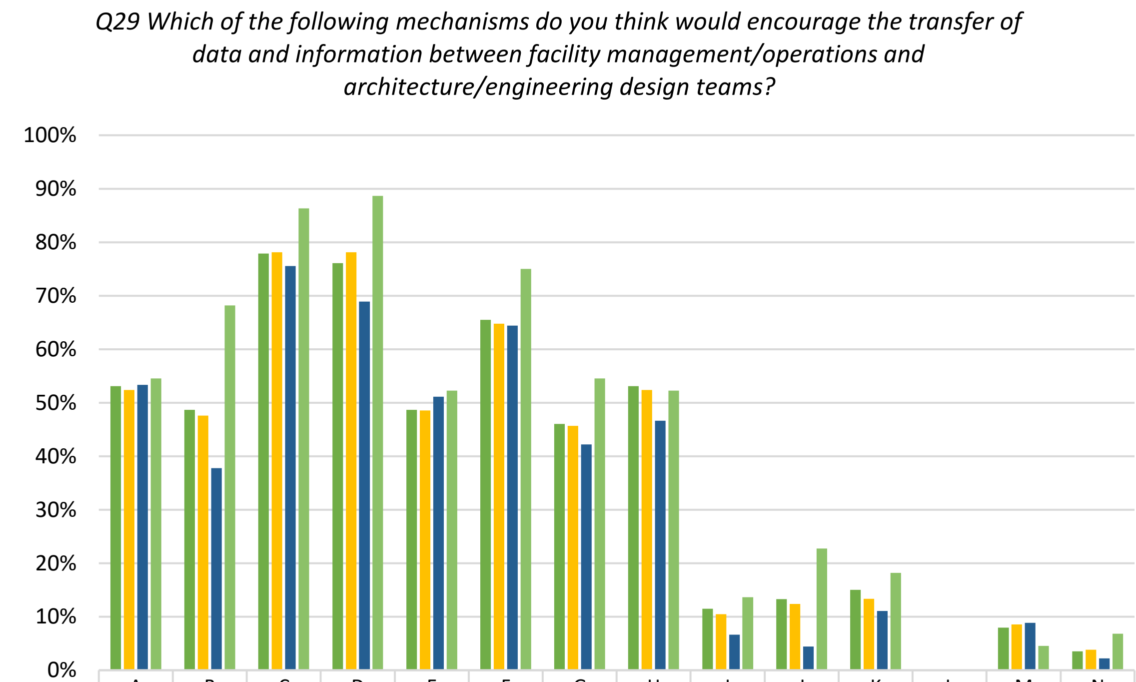
Question 28 asked respondents to evaluate the potential effectiveness of the listed classification systems to facilitate the sharing of data and information from FM to AE-design. Table 6.5 shows responses for the filtered US AE and FM only response pools for Question 28. This table was limited to these responses to be able to make a direct comparison between the two groups. In the table below, statistically significant variance between the two groups was highlighted in orange.

Table 6.15: Effective method for transmitting data and information

Question 28: To what extent do you think each of the following represents an effective method for transmitting data and information between facility management/operations and architecture/engineering design teams?														
	Extremely effective		**Very effective**		**Somewhat effective**		**Not so effective**		**Not at all effective**		**No opinion**		**Not applicable**	
	AE	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**	**AE**	**FM**
Omni-Class	0%	3%	0%	6%	5%	6%	0%	0%	2%	0%	74%	63%	19%	23%
Master-Format	2%	9%	12%	11%	14%	6%	0%	0%	2%	0%	51%	51%	19%	23%
Uni-Format	2%	3%	2%	3%	**0%**	**11%**	0%	0%	2%	0%	73%	60%	20%	23%
Uni-class	0%	3%	0%	3%	0%	3%	0%	0%	2%	0%	76%	69%	22%	23%
IFC	0%	3%	2%	6%	7%	3%	0%	0%	2%	0%	69%	69%	19%	20%
COBie	0%	3%	2%	0%	0%	9%	0%	0%	2%	0%	74%	66%	21%	23%
CI/SfB	0%	3%	0%	0%	0%	0%	0%	3%	2%	0%	76%	71%	22%	23%
CAWS	0%	3%	0%	0%	0%	0%	0%	0%	2%	3%	76%	71%	22%	23%
NRM	0%	3%	0%	0%	0%	0%	0%	0%	2%	0%	76%	74%	21%	23%
Prop.	3%	3%	0%	3%	3%	3%	0%	0%	5%	0%	70%	66%	20%	26%
Other	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Question 29: Transfer of data between FM/O and AE-design teams

Question 29 asked respondents to evaluate the potential for a range of mechanisms to encourage the transfer of data and information between FM and AE-design.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
All	53%	49%	78%	76%	49%	65%	46%	53%	12%	13%	15%	0%	8%	4%
US Only	52%	48%	78%	78%	49%	65%	46%	52%	10%	12%	13%	0%	9%	4%
US AE	53%	38%	76%	69%	51%	64%	42%	47%	7%	4%	11%	0%	9%	2%
US FM	55%	68%	86%	89%	52%	75%	55%	52%	14%	23%	18%	0%	5%	7%

A	Building Performance Evaluations (PBE)
B	Facility commissioning
C	Including facility managers during project program development
D	Including facility managers in design and construction phase project meetings
E	Including facility managers in the writing of performance specifications
F	Post Occupancy Evaluations (POE)
G	Providing a mechanism for the easy transfer of digital data or information between FM and A/E design teams
H	Requiring BIM deliverables to be handed over to facility managers or owners
I	Requiring COBie submittals to be handed over to facility manager or owners
J	Requiring IFC submittals to be handed over to facility managers or owners
K	Soft Landings or other project data exchange requirements (ex. Operations and Maintenance Support Information (OMSI))
L	I do not think there is a need to increase the transfer of data and information between FM/O and AE-design teams.
M	No Opinion
N	Other

Figure 6.24: Mechanisms to encourage the transfer of data and information

Respondents who indicated *Other* were asked to explain. Three respondents provided meaningful written comments to Question 29 which are provided below:

> **US-AE:** For this to be effective I would have to see a substantial increase in the ability to use technology.
>
> **US-FM:** have contractor (CM) turn over O&M content in a format that can be uploaded into the owner's work order management/inventory equipment system.
>
> **US-FM:** The introduction of the other systems may be very valuable, but no experience in their use.

Question 30: Additional comments

The last question of the survey asked respondents if they wanted to share additional thoughts related to the involvement of FM in AE-design processes. Twenty-one respondents provided additional meaningful comments (Table 6.6). These responses were categorised by the discipline in which the individual respondents identified themselves in Question 2. These comments generally revealed a belief that FM had the potential to benefit the AE-design process. This thematic sentiment matched findings from the literature review and semi-structured interviews that there was a perceived value in involving FM in AE-design processes.

Table 6.16: Further thoughts to share, written comments

Question 30: Do you have any other thoughts that you would like to share?	
Value of FM involvement in the AE-design process	
USAE	The earlier in the process facility managers are involved, including data transferring, the more information designers have to create a space that functions well for the client. However, this could also cause a reduction in creativity during early design stages. Balance is the key to any situation and having a facility manager at meetings can help to guide designers on a meaningful and efficient path to a successful building.
USAE	Facility Management should be involved in each stage of design and construction, however, each party involved should recognise their own knowledge set and relevancy during projects.
USAE	I think a more integrative approach to design has a great deal of merit and has the potential to develop buildings that truly go beyond the star architect approach and really begin to look at building design from a lifetime perspective. However, it seems … there is a long way to go to bring architecture from its traditional form to my vision. I have always been amazed that my experience has shown that there has been very little work in POE of any kind. I believe that the power of the "I" in BIM has enormous potential for both designers and FM and ultimately for the owner as the building matures but it will take a substantial increase of all to put information into the model and get it out. The matter of getting it out is also complicated by continued advancement in technology that very quickly makes the information that exists of little use because it’s outdated.
USFM	A grounded, experienced, and well-spoken facilities manager is the key to effective design for the client. In my case, the school district. We are in between the vision and the actual use of any project.
USFM	The facility manager is the one to take care of the building and make sure it runs properly. They need to know the building intimately. Before the project even gets started the design team should include the FM. The FM is the one who knows what is actually needed and what would work best for the people in their building.
USFM	In my experience the most successful projects have been those that have turned over to FM/O, in which have had FM involvement during the design phase. As a current FM and a former PM, FM's ultimately hold the keys at the end of the day and control the operations. PM and FM interaction during design is a key relationship for a successful bldg.
USFM	I always believed the architectural design process is supposed to solve problems or needs of the institution. When facility management has not been involved in the design and decision-making process the design has a tendency to create problems and solve them. Which is contradictory to the design process.
USFM	The more the facility Manager is involved the better the outcome will be for all parties.
USFM	The biggest disconnect I've seen is when "maintenance and operations" are not a part of the same team as the planning and or construction teams. When they are all under one umbrella, the communication is much better. The other organisation setup starts to create silos (especially in larger organisations). It's more of a project "hand-off" at that point. One group builds it, the other then gets handed the keys and is responsible for maintaining (which isn't great).
USFM	In my opinion the earlier and more frequently an FM professional is included in the design process the better the building will be for the owner/user group.
USFM	FM can bring a unique field perspective to A/E design teams, contribute to the design process, and improve the final product. Constructing maintainable facilities is often second to maintaining the design vision of a project or the aesthetic outcome the A/E has envisioned. Ideally the FM team needs to comprise architects and engineers that specialise in constructability and maintainability and essentially act as the grounding rod for the design A/E.
IEFM	W/O the involvement of FM in the design phase, it can lead to a very costly redesign once the employees give their feedback
USCM	From a general contractor’s standpoint, when we get the project, it often seems the architecture firm hasn't consulted at all with end users and what they want. Of course, there are several rules in places to limit end users and what they want but certainly more interaction through design and construction would be helpful.
USCM	I think that FM individuals are vital in the design process. I do not see it often enough in the CM/estimating process and think that it would create buildings with longer lifestyles. I believe AEs, FM, CM and Owner should be on board with the project and design from day 1.
US Sales	I think that FM field needs to include more in the entire process of construction and/or renovations. From a supplier side, I question a lot of designs with an FM degree/background.
Other	
USAE	Understanding the intended lifespan of a facility and also the maintenance needs, energy efficiency needs and other requirements (values) of the owner drive many of the design decisions from all aspects of the project.
USAE	Training during commissioning and CA would be useful as well as discussions about the complexity of controls during design.
USFM	The best FMs understand the design process. The best designers understand the FM/O process for buildings. The design process becomes petty and adversarial when uninformed designers and FMs hunker down in their own silos.
USFM	Designers often are not in touch with the realistic expectations of occupant administrations, leaving FMs in poor positions in regard to efficiently maintaining the new assets within the constraints of budgets that are driven primarily by goals other than building maintenance.
USFM	Having a complete preventative maintenance program will prevent long term cost.
UKFM	The profile of FM needs to be raised - this is a …challenging & rewarding profession; sadly, even other built environment professionals perceive this role to revolve about reactive emergency maintenance - the person with the broom & bucket.

6.3 Online Questionnaire Discussions

The following section summarises and contextualises the data collected from the online questionnaire. The following section further identifies themes within the data for inclusion in, or to be addressed by the framework discussed in subsequent chapters.

6.3.1 Discussion – Respondent Background Demographic Information

Questions 1 through 10 were used to determine the demographics of the respondents and the appropriateness of their responses to contribute to the survey. The survey portion of this research had the goal of receiving 100 valid responses. The survey received 143 responses but upon further review it was determined that 127 of these were valid responses. When filtered specifically for respondents who primarily work within the United States (total of 101 respondents), the respondents were almost equally split between AE respondents (50) and FM (51) respondents. The fact that respondents were almost equally split between AE and FM suggested an appropriate balance and validity to the responses.

Question 3 asked respondents about the length of their professional work experience. Within the full response pool, more than 50% of the respondents had more than 10 years of professional experience, and more than 70% had greater than five years of professional experience. This suggested the data represented the perspectives of experienced AE and FM professionals. However, when filtered for US AE-FM responses, there was a noted difference between the two groups when looking at respondents with more than 20 years of experience and 2 – 5 years of experience. This revealed that US based FM respondents had more experience than US based AE respondents. While this difference in professional experience was noteworthy, it reflected the expected demographic makeup of the two professions.

According IFMA, the average age of their members is 49 with 28 years of work experience, 16 of which are in FM (IFMA, n.d.-b). Whereas, according to the NCARB, the average age of architectural licensure candidates is 32 years old (NCARB, 2019). While this is not representative of the full profession, it suggested an AE profession younger and with fewer years of professional experience than the FM profession in the US, as was reflected in the responses.

Questions 7 and 8 asked respondents to evaluate how familiar they were with FM and AE professions, respectively. More than 85% of US AE-FM respondents said they were either *moderately* or *very* aware of the FM profession. And more than 90% reported they were either *moderately* or *very aware* of the AE profession. US FM vs AE responses were slightly more likely to be *very* aware of the AE profession than the FM profession. This was to be expected as not every AE project will have an FM associated it. However, any completed commercial or institutional project in the US will have had the involvement of an architect or engineer. Again, these results were expected and do not call into question the significance of the data.

Question 9 was seen by the author as one of the more important demographic related questions in the survey. It asked respondents if they had been involved in a new-build construction project or major refurbishment within the last five years. This directly spoke to the respondents' ability to speak to the relationship between FM and AE-design. Results indicated respondents were in a position to comment on the design process and the relationship of AE and FM. Ninety-seven percent of all respondents indicated they had worked on a new-build construction project or major refurbishment at some point in the past. When filtered by professional background, 100% of US AE respondents indicated such involvement, while 98% of US FMs did so. This spoke to the validity of the response pool and their ability to contribute to the research question.

Question 10 asked respondents how often they worked on design, construction, or refurbishment projects that included the involvement of a facility manager. As was expected, there was a statistically significant difference within the AE-FM response pool between the number of FMs that *Always* work on design, construction, or refurbishment projects that included the involvement of a facility manager and AE responses. This question was asked because if AE respondents *rarely* worked on projects that included the involvement of an FM, it would call into question the validity of the research aim and associated framework. For example, if AEs rarely worked on projects with an FM, it would be difficult to argue for a system that improves information sharing between FM and AE. The responses indicated that approximately 52% of US AE and FM respondents and 63% of all US respondents worked on design, construction, refurbishment projects that at least *occasionally* included the involvement of a facility manager. Furthermore, 48% of all US respondents indicated they worked on projects 50% or more of the time that included the involvement of FM. This suggested there was value in the research.

The author found the demographic/background section of this survey indicated the response pool was significantly balanced and experienced to support the validity of the data and its ability to meaningfully contribute to both the general body of knowledge and to underpin the development of the DSR artefact discussed in the following chapters.

6.3.2 Discussion – Primary Questionnaire Findings

The review of semi-structured interviews discussed in Section 5.2.3 identified five key areas of inquiry to be investigated in the subsequent online questionnaire:

1. What information is most beneficial to share between FM and AE-design?
2. When should information from FM be provided to AE-design teams?
3. In what form should information from FM be provided to AE-design?
4. How can information be classified to make it useable to external parties?
5. Can digital measures help facilitate the involvement of FM in AE-design?

These five points were used to summarise and contextualise key aspects of the data collected from the online questionnaire. The relationship between these five points and individual questions can also be seen in Table 4.6 of Chapter 4. The following section further identifies themes found within the data to be addressed by the DSR artefact. The five points of inquiry identified from the semi-structured interviews were addressed in the online questionnaire findings as follows:

6.3.2.1 What information would be most beneficial to share between FM and AE-design teams?

Multiple questions in the online questionnaire were used to inquiry about what information from FM would benefit the AE-design process. Particularly useful information related to this theme was found in Questions 19, 20, 22, and 23.

Question 19 was an open-ended question asking what information would be most helpful for FM to provide to AE-design teams. A thematic analysis of these responses found the following themes prevalent within the responses:

1. Information related to standard operations and maintenance procedures which will be performed once the facility is in operation.
2. Space and occupancy use of existing or similar facilities.
3. Historic records associated with maintenance and utility costs.
4. The knowledge and skill set of FM/O staff.
5. Internal facility specifications for materials, equipment, et cetera.

In addition, **Question 20** asked respondents about the usefulness of providing a range of specific types of FM/O data to AE teams during the design process. The analysis of this question suggested AE and FM respondents generally had similar views regarding what information and data from FM were most valuable to provide to AE-design teams. However, there was a striking disparity between FM and AE respondents when it came to the value of data associated with operational costs. FM respondents weighed the value of information related to operational and maintenance costs (life cycle costs) as more significant than AE respondents. In contrast, both AE and FM respondents saw information related to *occupancy use*, *user satisfaction,* and *energy use* as valuable.

Questions 22 and 23 asked respondents to consider the value of AE decision rationale being provided from AE-design to FM/O. Responses to both questions suggested *agreement* or *strong agreement* to both questions. These questions were also asked to determine if there was support within the respondent pool for tracking design decision-making process and design decision rationale.

Responses to these questions revealed there was a recognised benefit to FM involvement in the AE-design process; however, there was no definitive answer as to what information would be beneficial to share between FM and AE-design teams. This was perhaps to be expected as projects are often unique and have their own individual requirements. However, common themes became evident which could lead to the development of a common classification system linking knowledge and experience from a range of sources: project requirements, FM related data, external data, AE-design-related data, et cetera.

6.3.2.2 When should information from FM be provided to AE-design teams?

Multiple questions in the online questionnaire were used to inquiry about when information from FM should be provided to AE-design teams. Useful information related to this theme was found in Questions 24, 25, and 30.

Question 24 asked respondents to evaluate the most useful project phase(s) for FM data and information to be shared with AE-design. While there was support for the sharing of information to take place across all project phases, responses suggested early involvement was viewed as more valuable than later involvement, with an ongoing need for some continued involvement. This result was expected as early design decisions have a more pronounced impact on the effectiveness and lifecycle costs of a project (Ipsen et al., 2021; Schade et al., 2011). It was therefore logical that early phases were seen as more important for the sharing of information between FM and AE.

Question 25 asked respondents to evaluate the most useful project phase for data and information to be transferred from AE to FM (the inverse of question 24). Responses suggested an ongoing need for the sharing of information from AE to FM during all project phases. In contrast to the previous question, when asked about the sharing of information *from* AE *to* FM, responses were spread across all project phases. Again, like Question 24, this result was not unexpected as an FM's involvement in a project continues through the full lifecycle of a building and does not taper off towards the end of the design phase as would AE's involvement. Based on this feedback, any solutions proposed to fulfil the research aim must accommodate information transfer across a project's full timeline.

6.3.2.3 In what form should information from FM be provided to AE-design?

Several questions in the online questionnaire were used to inquiry about what form should information from FM be provided to AE-design. Useful information related to this theme was found in the responses to multiple questions.

Question 13 asked respondents to describe in writing how design decisions were documented. These written comments thematically suggested a clear reliance on text-based documents (such as emails and meeting minutes) and handwritten notes for documenting decision-making processes. In the context of this research, this appeared to be a fundamental aspect of current industry practices that must be considered and addressed in any attempts to address the stated research aim.

Questions 14 and 15 asked respondents about the use of databases to track lessons learned from past projects. Almost half (45%) of US AE-FM respondents indicated they did not maintain a formal record of lessons learned from past projects or were unaware if they did. This was noteworthy in the context of this research because if lessons learned from past projects were not maintained in an easily accessible manner, such as a searchable database, it would be difficult to apply those lessons to future projects.

The thematic analysis of the written comments suggested a lack of resources and time as the main barrier to maintaining a record of lessons learned from past projects. Additionally, nine responses indicated lessons learned were maintained as implicit knowledge within the minds of the employees. Implicit knowledge is not easily searchable or able to be applied to disparate projects, outside of the mind of the individual who holds the knowledge. Furthermore, implicit knowledge often leaves with individuals when they change jobs, retire, etc. To some degree, the reliance on implicit knowledge in the AE-design process, and interactions between FM and AE-design, was that which this research sought to address.

Question 16 built on questions 14 and 15 and asked respondents what they thought would be the ideal method for tracking lessons learned from past projects. P*roject notes* (49%), *spreadsheets* (44%), and *generic databases* (42%) were somewhat equally selected in the percentage of US AE and FM respondents. Noteworthy was the fact that no category was selected by a clear majority of respondents as the ideal method to track lessons learned. Project notes was selected with the highest percentage (61%) of respondents by US FMs.

Questions 17 and 18 related to the documentation of crucial project decisions and requirement changes made over the course of the project.

Responses to **Question 17** indicated only 55% of US AE and FM respondents used a process to track design decisions and or project requirement changes. Additionally, respondents were asked to describe in writing what processes they used, if they used one, or why they did not document design decisions or project requirement changes if they did not. The most significant theme to come from the written comments was that most respondents relied on written meeting minutes and project notes to track design decisions or project requirement changes. Most comments indicated notes are kept in emails or text documents, while a few comments mentioned the use of spreadsheets. Comments written on project drawings was also mentioned multiple times.

Question 18 asked respondents what they thought would be the ideal method for keeping track of design decisions and project requirement changes (discussed in Question 17). Respondents were asked to consider this question regardless of whether they kept track of such lessons themselves. There was a spread of responses within US AE and FM respondents with *Project notes* (62%), *Spreadsheets* (40%), *Generic database* (30.08%), and *BIM related software* (31%). Within these results there was a statistical significance in the difference between US AE and US FM respondents with regards to the use of *CAFM or related software*. Twenty percent of US FM respondents (vs 6% of US AE responses) indicated they see *CAFM or related software* as an ideal method for tracking design decisions and project requirements. This was not a surprise to the researcher as AE teams are much less likely to use or be familiar with CAFM software as opposed to the FM respondents. What is noteworthy is that even so, only 20% of US FMs saw CAFM as an ideal method for tracking design decision and project requirement changes.

Questions 17 and 18 were important in the context of this research because if project requirements and associated design decisions were not adequately tracked, it is impossible to evaluate the outcome of design decisions. If you were not aware of the requirement that drove a design decision, or why a design decision was made, it would be impossible to know if the requirement was met. Similarly, if project requirements were not adequately tracked, it would be difficult to provide relevant information from FM to AE appropriately.

Question 21 asked respondents if they thought the digital exchange of information was sufficient to realise the potential benefits of FM/O involvement in the AE-design process. The purpose of the question was to determine whether respondents thought face-to-face interaction between AE and FM was necessary, or if instead, the digital transfer of data was sufficient. A majority (56%) of US AE-FM respondents *disagreed* or *strongly disagreed* that the digital exchange of information would be sufficient. Responses suggested at a minimum, the digital exchange of data from FM to AE-design would require some level of face-to-face interaction to interpret the data. This question was particularly important in the context of this research as it related to how the aim can be addressed. Furthermore, at the onset of this research project, it was anticipated that the solutions called for in the aim would be found in the development of a digital tool that acted to facilitate the sharing of information between FM and AE in lieu of in-person interactions; however, data gathered through the interview process and questions such as this suggested a digital tool by itself would be insufficient and that any proposed solution that fulfilled the aim must accommodate both digital and interpersonal exchanges between FM and AE.

From the data collected, it is clear both FM and AE professionals stored data and knowledge in a range of forms and any attempts to address the research aim must be able to accommodate a range of information types and storage mechanisms. Furthermore, any sharing of digital data needed the support of in-person interactions at specific project points to explain data. And finally, any proposed solutions must fit within existing workflows.

6.3.2.4 How can information be classified to make it useable to external parties?

Questions 26 – 28 were asked to help evaluate whether an existing building systems classification method could be used to act as the basis for a DSR artefact that fulfilled the aim. The responses to these questions suggested this is not the case, or at least suggested that no one single existing system stands above the rest.

Question 28 asked respondents to evaluate the potential effectiveness of common building system classification systems to facilitate the transformation of data and information from FM to AE-design. In response to Question 28 a clear majority of US AE and FM respondents indicated they have *no opinion* (60% - 70% in all but the case of MasterFormat with 51%) regarding the potential for the listed classification systems to act as an effective method for sharing data and information between FM and AE.

To this end, any proposed solutions that fulfilled the aim must be able to work within existing systems, as no single system stands above the rest, but must also be able to transmit knowledge as well as data and information. Furthermore, projects are often unique and have their own individual requirements – thus any attempt to address the research aim must be customisable.

6.3.2.5 Can digital measures help facilitate the involvement of FM in AE-design?

Question 11: Responses to Question 11 suggested limited use of AIMs within the sample pool, even within the filtered US only FM responses. In the context of this research, the author felt this limited the current potential for an AIM to form the basis for solutions that fulfilled the research aim. The use of an AIM to bridge the gap between AE and FM may be more applicable in the future and presents a potential area of future research. Within the written responses to this question, lack of resources was indicated as a common reason AIMs were not maintained. While the use of AIMs may currently be limited in their ability to address the research question, this issue of resources and lack of technical ability was important in relation to the development of solutions that fulfilled the research aim.

Question 16: When US FM and AE respondents were compared in Question 16, the only statistically significant difference between the two groups was related to BIM. Forty-five percent of US AE respondents (vs 24% of FMs) indicated they thought BIM related software represented an ideal method for keeping track of lessons learned from past projects. This may reflect the fact that the US AE respondent pool was much younger than the FM respondent pool and therefore more likely to be comfortable using BIM, or because AE respondents were also more likely to use BIM related software in their daily work experiences. The discrepancy between US AE and FM responses regarding the use of BIM did not come as a surprise given these suppositions.

However, this result was particularly interesting when compared to the responses in Question 11 related to AIMs. In Question 11, 43% of US FM respondents indicated they worked for an organisation that maintained an AIM. However, only 24% of these same respondents saw BIM related software as an ideal method for tracking lessons learned. This could be for a variety of reasons that were not evident in the data. For instance, it may because they do not associate AIMs with BIM related software, or simply because while they maintain an AIM, they do not see it as an appropriate method for tracking lessons learned.

Like the previous questions, the written comments associated with Question 16 provided additional insight. These written comments thematically suggested any system for tracking lessons learned must be easily managed and updated. Furthermore, any such system should fit within existing workflows.

Question 29: Of note in the responses to Question 29 were the low levels of support for COBie, IFC submittals, Soft Landings, or other project data exchange requirements. When these results were viewed with those related to the digital transfer of information, Question 21, they suggested any digital transfer would need to be supported with in-person interactions at specific project points to explain the data.

6.4 Chapter Summary

The above analysis of the online questionnaire, in conjunction with the discussion of the semi-structured interviews in Chapter 5, reiterates the findings from the literature review. They further validated the research aim and objectives. Findings from both the semi-structured interviews and online questionnaire revealed the following:

1. There is a recognised benefit to FM involvement in the AE-design process.
2. FM involvement should be ongoing throughout the design process, but with a focus on early design phases.
3. Both FM and AE professionals store data and knowledge in a range of forms and any attempts to address the research aim must be able to accommodate a range of information types and storage mechanisms.
4. Digital tools focused on storing information vs data, may provide a mechanism for addressing the research aim and objectives.
5. Projects are often unique and have their own individual requirements – thus any attempt to address the aim must be customisable.

The data analysis of the semi-structured interviews and online questionnaire represented an analysis undertaken to provide a basis for the conceptual framework and refinement of a DSR artefact that fulfilled the research aim. The artefact was developed to fulfil the research aim and the semi-structured interviews and survey acted as supporting research. To this end, the following chapters build on the knowledge gained from the interviews and questionnaire and discuss the development and refinement of the framework and DSR artefact.

7. FRAMEWORK – DESIGN DECISION SUPPORT SYSTEM

7.1 Chapter Introduction

Chapter 2 of this thesis reviews literature related to the relationship between FM and AE in the design process. It further connects the literature review to the research aim and objectives associated with this thesis.

This is followed by Chapters 3 and 4, which establish the research methodology and research design used for this thesis. Chapters 5 and 6 then discuss findings from a series of semi-structured interviews and an online questionnaire. This chapter, Chapter 7, reflects on these previous chapters and the research undertaken to this point. It further seeks to contextualise findings from the literature review and the data analysis into a DSR framework which supports building design decisions by facilitating knowledge and information sharing between FM and AE-design. To aid in discussion and explanation of the framework, it is conceptualised as a Design Decision Support System (DDSS) and associated Design Decision Support Tools (DDSTs). The development of this framework and associated subsystems represents the DSR artefact associated with the research methodology.

7.2 Research Aim and Objectives and Associated Findings Summarised

In Table 7.1 below, the objectives are summarised in conjunction with the research findings. Each research objective is identified with the primary area of the thesis from which the findings associated with that objective originate. The objectives and associated findings are provided here as they form the basis for the framework described in this chapter.

From the analysis of the interviews and questionnaires in the previous chapters, the findings from the literature are supported. Both sets of findings point to several areas of focus that one can look to for addressing the research aim. However, within the context of a single research study they cannot all be addressed due to research time constraints and resource limitation. As an attempt to accommodate these constraints, this chapter describes the development of a broad conceptual framework that addresses the range of findings from the previous two chapters (Chapters 5 and 6), as well as the broader question of FM involvement in the AE-design process.

Table 7.1: Research objectives reviewed with initial findings

Research Objectives Reviewed with Initial Findings and Their Sources				
Literature Review	**Interviews**	**Questionnaire**	**DDSS Framework**	**Research objectives and associated findings**
●	○	○		**1. Identify barriers to sharing facility management and operations information and knowledge with AE-design teams.**
	●	●		a. Lack of internal time and resources
	○	●		b. Technological limitations within AE and FM/O teams
○	●	○		c. Lack of awareness
	●	●		d. Existing data sharing approaches are haphazard in nature and lack a formal structure
	●	●		e. There is a limited use of formal design decision-making processes for FM/O data to be integrated into (that is to say, there is nothing for it to be integrated into).
○	●	○		f. There is a lack of knowledge of each other's day-to-day practices (and how to share that)
●	○	○		g. Post-occupancy evaluations are not commonly done
	●	●		h. Data, information, and knowledge is not stored in a manner that is easy to find or share
	○	●		i. Design decisions are being made without a formal decision-making process
		●		j. Projects are often unique and have their own individual requirements limiting the ability to share
○	○	●		**2. To identify what information is available from facility management and operations to support AE-design decision-making process.**
	●	○		a. Operations procedures and requirements
	○	●		b. What types of data and information are tracked or of interest to the client
	●	○		c. Maintenance procedures and requirements
○	●	○		d. Skillset of FM/O staffing
	●	○		e. Preferred or existing locations of essential equipment
	●	○		f. Daily FM/O practices
	●	○		g. Facility standards with examples of how they are maintained
	●	●		**3. To identify how facility management and operations information and knowledge can be shared with AE-design teams.**
	●	●		a. FM/O data provided early in the design process (PD, SD, DD) with ongoing interaction is preferred.
	●	●		b. A transfer of digital data with in-person interactions at specific project points to explain data is preferred.
	●	●		c. Written text in project notes or spreadsheets is the most utilised form of data storage.
			●	**4. To develop and validate a conceptual framework that supports AE-design decisions by facilitating information and knowledge sharing between facility management and operations and AE-design teams.**

● The primary source of finding
○ A secondary source of finding

The broader framework, including a series of sub-systems or components, addresses the following findings from the semi-structured interviews and questionnaire. These specific findings and their justification for inclusion in the framework and sub-systems are presented below with elaboration on their connection to the original research question. Research findings addressed through their development include the following:

1. There is a general lack of knowledge of each discipline's day-to-day practices and the professional knowledge from each that would be beneficial to share.
2. Data, information, and knowledge is not stored in a manner that is easy to find or share between disciplines.
3. Design decisions are being made without a formal decision-making process and supporting information.
4. A transfer of digital data and information with in-person interactions at specific project points to explain the information is preferred.
5. Any solutions must fit within existing workflows.
6. The capture of decision rationale is valuable in providing context for FM/O data and information and to be able to assess design decisions based on FM/O feedback.

Item six from the list above needs additional context and elaboration. Particularly in reference to the study's research aim and objectives, which suggest a focus on the information being transferred *from* FM/O *to* AE-design, where item six refers to the transfer of information *from* AE-design *to* FM. Providing data from FM/O to AE-design only tells part of the story, and in fact, it may be argued it does not accurately tell the story at all. Without the complete loop – design decisions, assessment, operations data – the research aim cannot be fully addressed.

The transfer of knowledge from FM *to* AE-design to inform design may help inform design decisions themselves, but it does not help evaluate or assess those same decisions, either during the initial design process or post-occupancy. Furthermore, it limits the ability for future information transfers to help with future design decisions on future projects. One cannot learn from these design decisions and reuse that knowledge if the decision rationale associated with them is not tracked. Therefore, it is important that design decisions are informed through the transfer of knowledge and information from FM to AE-design, but it is also necessary to track those same decisions.

The importance of sharing design decision rationale from AE to FM, in addition to sharing information from FM to AE, is reinforced by survey questions 22 and 23, as discussed in Chapter 6. In question 22, 86.73% (98 out of 113) of respondents *Agreed* or *Strongly Agreed* that it would be beneficial to the facility operations and maintenance process for AE-design decision rationale to be provided to FM/O teams. Furthermore, 86.61% (97 out of 112) of respondents *Agreed* or *Strongly Agreed* that it is necessary to be aware of the rationale behind facility design to evaluate a facility's design performance and design quality effectively.

By tracking design decisions and their rationale, it is also possible to evaluate the information the assumptions were based on. For instance, it is possible to evaluate whether the information that informed the design assumptions was correct or faulty. This is necessary to evaluate whether a design decision is good or not. A good decision might look bad, or vice versa, depending on the accuracy of the information the decision was based on. Design assumptions are therefore embedded and visible in the proposed framework to help assess design intent. For these reasons, the capture of decision rationale to be shared with FM/O teams, as well as future design teams, is seen as important in the context of this research and associated framework.

7.3 FM/O Inputs in the Design Process

The findings associated with the research objectives 1 – 3 (Table 7.1) form the basis for the development of the framework in this chapter. This framework represents the *finding* associated with research objective 4 (Table 7.1). In seeking to address objectives 1 – 3, through the development of the framework noted in objective 4, it is important to reaffirm the context and limitations of this research. While this research recognises the complexity of the building design and construction process, it is focused on the benefit of improved information and knowledge sharing between FM/O and AE-design teams. In fulfilling the research aim, this research is focused primarily on AE-design and the sharing of FM/O information and knowledge to help inform AE-design decision-making as represented in Figure 7.1 (Figure adapted from Kiviniemi (2005)).

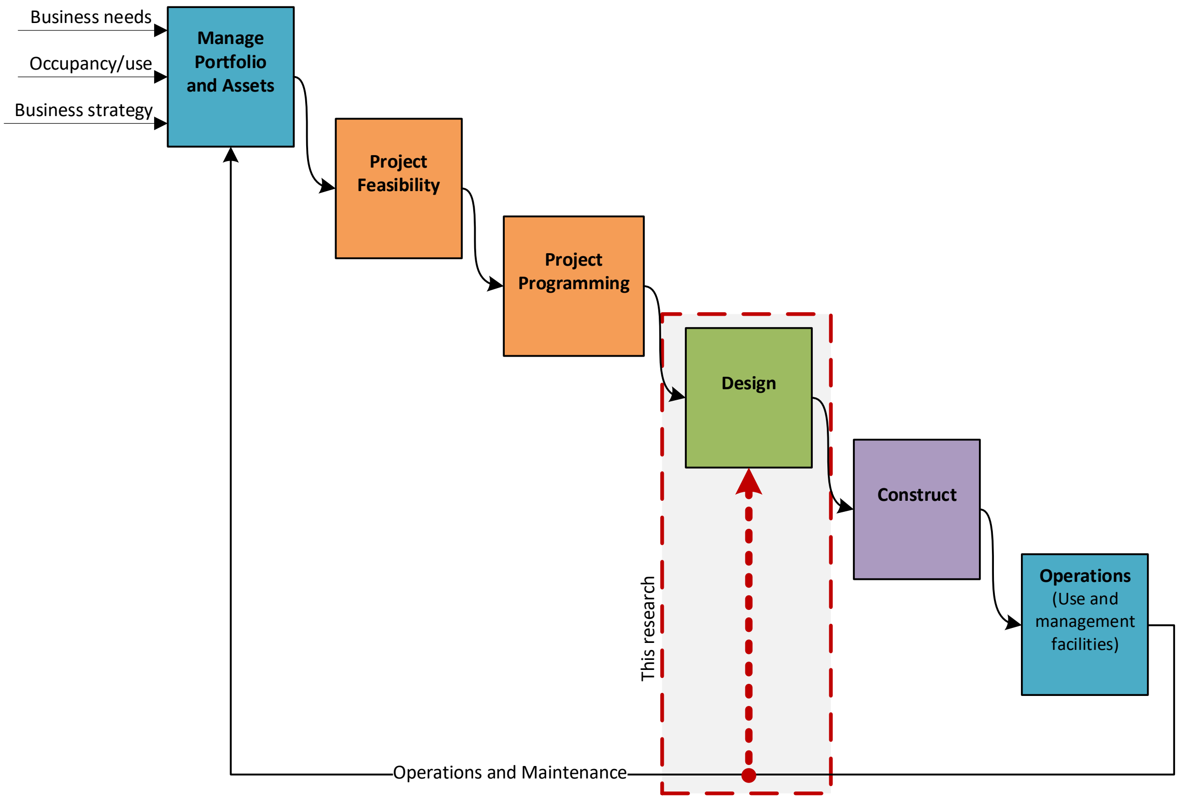


Figure 7.1: Scope of framework and associated research
(adapted from Kiviniemi, 2005)

7.3.1 Design Constraints

According to Lawson (2005), there are four basic categories of design problem generators: *Clients*, *Users*, *Designers*, and *Legislators*. Each of these design problem generators imposes its own constraints upon a design solution but do so with their own degree of rigidity. With the most rigid of these imposed via legal requirements, such as building codes, and the most flexible being those generated by the designers themselves, such as purely aesthetic considerations (Figure 7.2, adapted from Lawson (2005)). Any design problem can be seen as being built up of constraints. In fact, it is these design constraints that define a design problem. Lawson suggests the purpose of constraints is to ensure a design solution performs its desired function as well as possible.

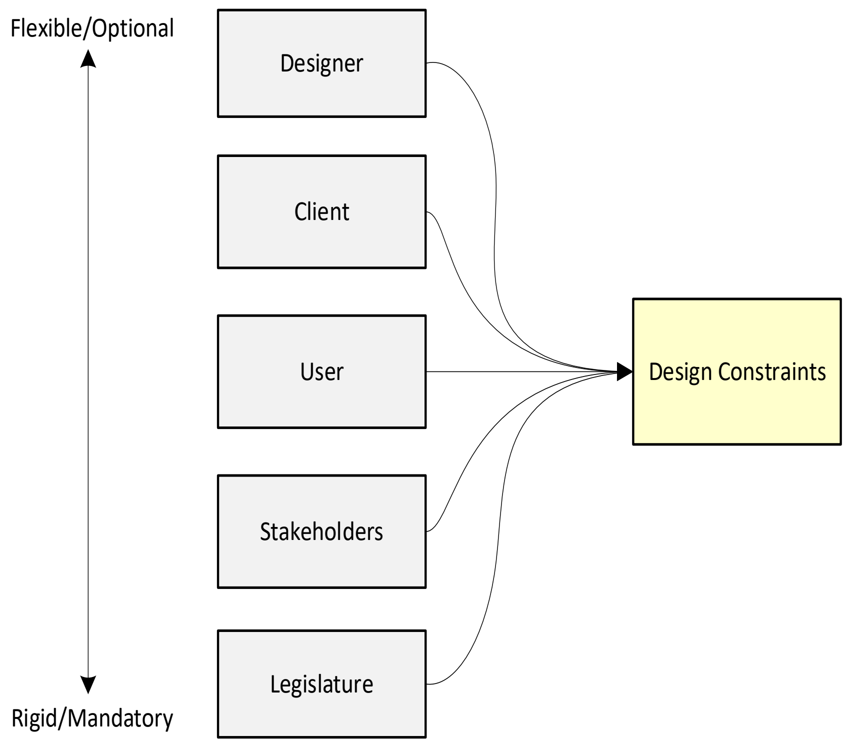


Figure 7.2: Design constraint generators

These types of constraints can be categorised as either *internal* or *external.* For each of the constraint categories listed above, there exists both internal and external constraints. Of these, internal constraints are the most flexible because they are self-imposed. While external constraints, such as those by legal requirements, are the most rigid.

When design is approached as a problem-solving exercise (Dorst & Lawson, 2013; Papanek, 1985; Rowe, 1994; Simon, 1996), a project's constraints shape the nature of the problem(s) being solved. In attempting to solve these problems, a designer must take-in and consider a range of inputs beyond the constraints themselves. For example, within a typical building design project undertaken by an AE-design team, designers are asked to consider a range of internal and external factors and data inputs, such as: legal requirements, programmatic requirements, sustainability requirements, stakeholder or user requirements, cost, aesthetics, the means and methods of construction, laws of nature and physics, user needs, the professional body of knowledge, or standard details (Figure 7.3). This is not an exhaustive list but serves to represent the range of inputs a designer may consider when making a given design decision. Within the context of this research, and the framework discussed in this chapter, this thesis is focused on how information and knowledge from existing facilities (that is to say, from FM/O) can inform and improve design decisions. This does not suggest the other inputs are not equally or more important, or worth considering in their own right, rather, it is simply the focus of this research and is reiterated here to clarify the focus of the framework.

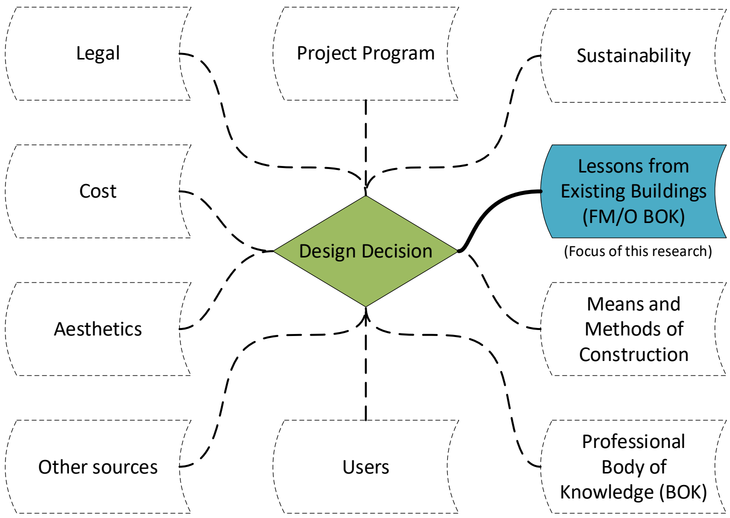


Figure 7.3: Examples of AE-design decision considerations

7.3.2 Business Process Reengineering

Because this thesis, and its associated research aim, seek to improve an existing business process – the AE-design process – through the development of a solution to facilitate information sharing between FM and AE-design, Business Process Reengineering (BPR) research is looked to for guidance on how to do so. Business Process Reengineering methodologies provide a set of techniques and guidelines which enable the reorganisation of business processes and activities (such as the AE-design process). Valiris and Glykas (1999) suggest there are two main categories of BPR, depending on the perspective they take: 1) the management accounting perspective which uses IT as an enabler for process reengineering, and 2) the Information Systems (IS) perspective that reorganises business processes so that IT has the highest possible impact.

Valiris and Glykas (1999) further suggest business process redesign can be achieved in one of two modes: incremental and radical. The former takes advantage of methodologies for improvement and simplification. Such methodologies aim to improve what already exists in a process. The latter, radical change redesign, fundamentally challenges existing processes. In the context of this thesis, an incremental or continuous improvement methodology is adopted due to the established nature of the AE-design process. Furthermore, the findings from the semi-structured interviews and online questionnaire found that any proposed solutions to the research aim, should fit within existing workflows. Therefore, rather than attempt to fundamentally reorganise the design and construction process, the use of IT as an enabler that works within existing design processes is proposed. Applying and adapting the work of Poudelet, Chayer, Margni, Pellerin, and Samson (2012) in an FM – AE context, it is suggested that a framework that fulfils the research aim should:

1. be simple to use and adaptable to common design processes and workflows;
2. provide results that are simple to understand and apply;
3. use plain language terminology that is understandable by all stakeholders;
4. focus on the whole life of a facility;
5. incorporate and maintain design decision rationale;
6. allow for the feasibility of project needs and requirements to be reconfirmed at all stages of a gated process;
7. present and visualise data, information, and knowledge appropriately;
8. accommodate the transfer of knowledge between different professionals and different professional disciplines;
9. allow design professionals to create new knowledge from new information and data when provided from outside sources;
10. provide mechanisms for indexing, searching, and retrieving design cases; and
11. support design knowledge capture and reuse.

Additionally, due to its collaborative and complex nature, Abrassart and Aggeri (2007) suggest attempts to improve the design process must consider the sequencing of activities, the validation process, and shared responsibilities among the design team and owner (as cited in Poudelet et al., 2012). Based on these requirements, the data analysis from the preceding chapters, and the literature review, the development of a DDSS framework is discussed below.

7.3.3 Selection of a Design Decision Support System

Boecker et al. (2009) describe the building design process as consisting of multiple complex tasks and processes. The AE-design process requires a significant amount of technical knowledge and subjective input from the design team. Singhaputtangkul (2017) finds that AE teams often face various decision-making problems such as a lack of communication and difficulty adhering to project requirements without an established decision-making process. Yang, Wang, Dulaimi, and Low (2003) further suggest it is difficult for designers to consider all the criteria associated with a building design without an effective way to manage trade-offs. Singhaputtangkul and Low (2015) suggest a need for building design teams to mitigate decision-making problems and propose that a decision support tool can help do so.

The data collection associated with the semi-structured interviews and online questionnaire suggested that the respondent pool largely did not use formal decision-making processes. Furthermore, the findings indicate that both AE-design and FM teams do not store data, information, and knowledge in a manner that is easy to find or share between disciplines. However, they felt that the sharing of information and knowledge from FM to AE has an unrealised potential benefit. The framework and associated subsystems described in this chapter are presented to help facilitate the sharing of information and knowledge from FM to AE. Because it does so with the intention of supporting design decisions, it is described herein as a design decision support tool.

A decision support system (DSS) generally refers to the role of computers or information technology systems (IT) systems in supporting business or organisational decision-making processes. However, according to Keen (1980), the term is not well defined. For some, a DSS refers to an interactive system used by business managers that provides support but is not a system. Kroeber and Watson (1987) define a DSS as an "interactive system that provides the user with easy access to decision models and data to support semi-structured and unstructured decision-making tasks" (as cited in Han & Kim, 1989). In this capacity, DSS represents a mechanism for "augmenting human intellect." Described by Engelbart (1962, p. 1) as "increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems." Engelbart defines increased capability as "more-rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex, speedier solutions, better solutions, and the possibility of finding solutions to problems that before seemed insolvable."

A DSS that specifically supports design decisions can be referred to as a Design Decision Support System (DDSS). Therefore, a DDSS that seeks to address the identified research aim must address the unique characteristics of design decision-making processes.

Arnott and Pervan (2005) identify seven suggestions of different DSS types:

1. Personal decision support systems;
2. Group support systems;
3. Negotiating support systems;
4. Intelligent decision support systems;
5. Knowledge management based DSS;
6. Executive information systems/business intelligence; and
7. Data warehousing.

In the context of this thesis, a knowledge management-based DSS is suggested as the most appropriate form of DSS to address the research aim. Arnott and Pervan (2005, p. 15) describe a knowledge based DSS as "decision support technologies can aid knowledge storage, retrieval, transfer and application by supporting individual and organisational memory and inter-group knowledge access (for example, with electronic bulletin boards, knowledge repositories, discussion forums, knowledge directories, expert systems and workflow systems)."

7.3.4 DDSS Framework and Choice Architecture

In the context of the DDSS conceptual framework presented below, the BPR process described above relates to the concept of c*hoice architecture* and associated choice *nudge(s)* as described by Thaler and Sunstein (2009). Thaler and Sunstein describe a *Choice Architect* as one who organises "the context in which people make decisions" (p. 2). They propose that while a building architect cannot design a perfect building, they can make subtle choices that provide beneficial impacts on a building's occupants. For example, by designing exit stairs that are attractive and comfortable to use, more occupants are likely to take the stairs rather than an elevator. In a similar manner, choice architects do not dictate a user's choice; rather, they seek to create a system which enables a decision maker to be able to make better decisions. According to Thaler and Sunstein, choice architects do not try to predetermine people's choices. Rather, they self-consciously attempt to move people towards better decisions. They call this a *nudge.*

According to Thaler and Sunstein (2009, p. 6), a nudge is "any aspect of the choice architecture that alters people's behaviours in a predictable way without forbidding any options…" Furthermore, they suggest that to be considered a nudge, interventions must be easy to avoid. To Thaler and Sunstein, "nudges are not mandates" (p. 6).

Working within the context of existing AECO processes, the DDSS can be seen as setting up a choice architecture which seeks to nudge AE-design towards better design decisions by facilitating better integration of FM information and knowledge into AE-design processes. The proposed DDSS does not dictate or mandate its use in a specific manner; rather, using the science of decision making, it sets up a system which nudges users toward better decision making. This concept is central to the development of the DDSS and will be referred to repeatedly below. The concept of a nudge fits directly within the context of the BPR incremental improvement methodology discussed above as it works within existing systems to make changes to existing business processes.

Due to the complexity and innumerable decisions associated with a typical building design project, a choice architect, or a DDSS, cannot shape every design decision. However, a DDSS can influence designers to make more informed decisions. That is to say, it can *nudge*. Furthermore, the author proposes that it would be overly paternalistic (a term used by Thaler and Sunstein), for the DDSS to attempt to influence a designer's behaviour directly or overly, or narrowly direct their design proposals and solutions. Therefore, the proposed framework attempts to balance a libertarian view (another term used by Thaler and Sunstein in reference to choice architecture) of the design process with a paternalistic view.

The DDSS described herein allows designers or design teams to be able to go their own way without limiting their creative freedom. However, simultaneously, it seeks to nudge them in the direction of better decisions or better decision-making processes. It has been shown that even experts routinely make poor decisions when faced with complex multi-variable decisions that have limited, or long event horizon feedback. In a building design context, this is evident in research showing that LEED-certified buildings often use more energy than non-LEED buildings (Oates & Sullivan, 2011; Scofield, 2013), or simply from the fact that buildings often do not perform as intended or as designed, and often cost more to construct and operate than is budgeted (Mills, 2011; Ornetzeder et al., 2016). To this end, the author acknowledges that every design decision cannot be controlled, but that AE-design teams can be nudged towards better decision-making processes. And more importantly in the context of this thesis, can be nudged towards better utilisation of information and knowledge shared from FM into AE-design processes with the goal of making more informed decisions.

7.4 DDSS Framework Overview

Design teams work in collaboration with a range of stakeholders over the course of a building design and construction process. According to the AIA, this process typically consists of eight phases which work from broad to specific: 1) Pre-Design, 2) Site Analysis, 3) Schematic Design, 4) Design Development, 5) Construction Documents, 6) Bidding or Negotiation, 7) Construction Contract Administration, and 8) Post-Construction Services (Hayes, 2014). Within these steps, project requirements and constraints are initially defined in a planning phase, after which an initial design is developed into detailed solutions through a series of subsequent phases that lead to construction, occupancy, and sometimes, post-occupancy analysis (Figure 7.4).

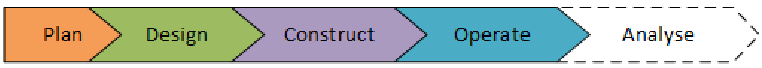


Figure 7.4: Simplified conceptualisation of traditional design and construction process

This characterisation of the building design and construction process presents a false image of a sequential process where each project phase clearly builds on the previous. For example, project requirements are set in the planning phase, project needs – as defined in planning – are solved in design, the design is constructed as defined, and then occupied. This traditional sequential characterisation of the AECO process similarly suggests a one-directional flow of information where information is *pushed* from external systems to AECO bodies of knowledge and new projects (Figure 7.5).

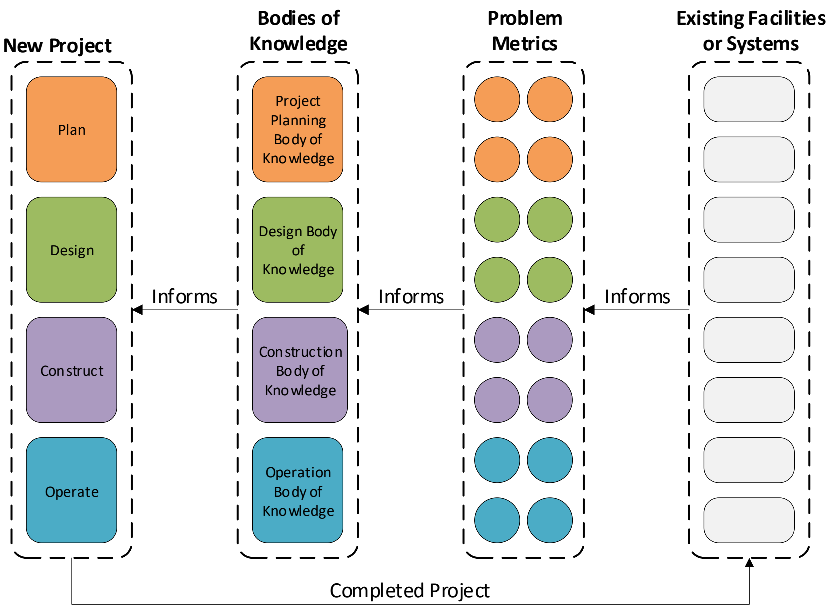


Figure 7.5: Traditional view of AECO data, information, and knowledge flows

While this representation may be conceptually accurate, it is rarely reflected in practice. A more accurate representation of the process is captured in a statement by Daniel Fallman (2003): "The building design is a deeply iterative process – constant dialogue between ideas, analysis, synthesis, and evaluation. It is indeed as much problem setting as problem-solving" (as cited in Kiviniemi, 2005).

In response to the iterative nature of the design and construction process, Kiviniemi and Fischer (2004, p. 3) suggest the process "should be described as partly parallel activities… Inside this parallel process, the progress on the detailed level is a spiral of iterations." A representation of their parallel activity view of the design-construction process, with an analysis phase added by this researcher, is seen in Figure 7.6:

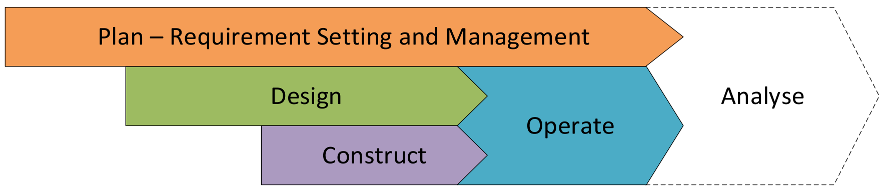


Figure 7.6: Design and construction process as partly parallel activities

The author proposes that this view of the design-construction process more accurately reflects the reality typically found in practice; however, it still relies on a series of sequenced activities that are increasingly uncommon in modern design and construction practices. When viewed as parallel activities, a representation where each project phase begins together and occurs together through much of the project may be more accurate (Figure 7.7).

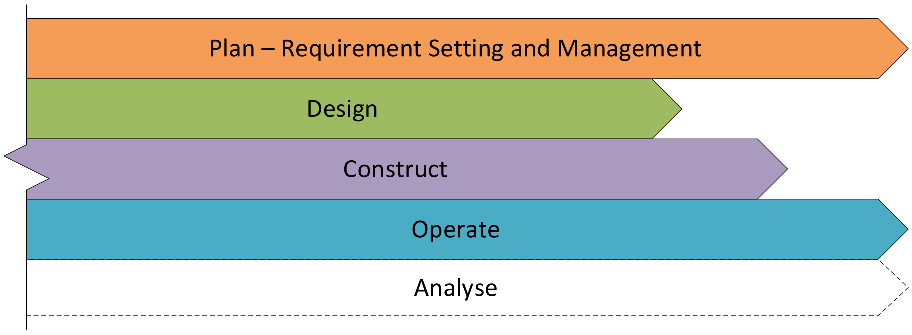


Figure 7.7: Design and construction process conceptualised as parallel activities

This representation more accurately reflects the ideal timing of modern AECO activities related to the design and construction process, but it fails to reveal the true nature of the interaction between disciplines. By representing each individual process in parallel with the others, it incorrectly suggests AECO disciplines act in silos. A more accurate representation of the process shows AECO discipline activities as an interconnected web in which each sphere of activity directly interacts with the others – to varying degrees over the course of a project (Figure 7.8).

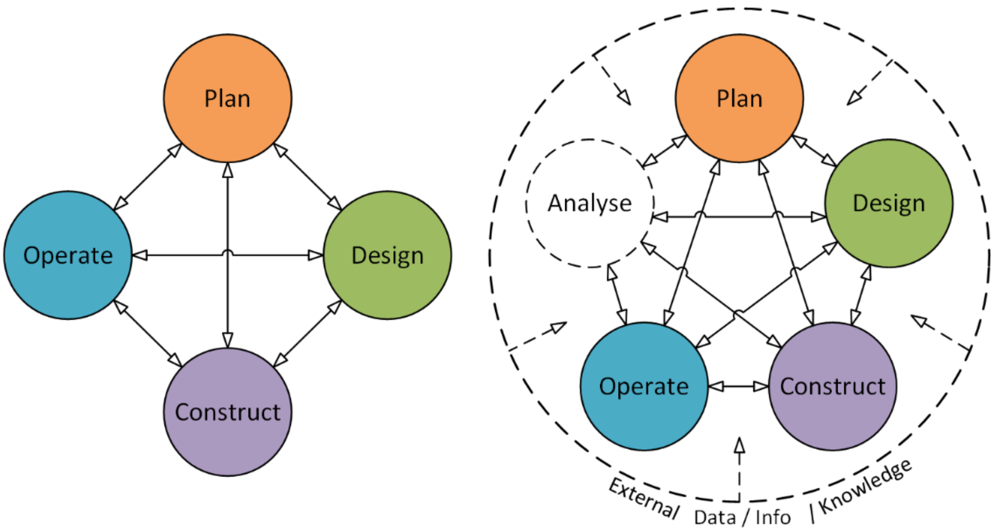


Figure 7.8: Realms of activities as an interconnected web (left) / The role of analysis and external data added (right)

This representation of the design-construction process, as an interconnected web, in which analysis is included as an essential sphere of activity sets the foundation for a DDSS framework that seeks to link FM/O information and knowledge more integrally with early design decisions and project phases. An overview of how this may reshape the design-construction process is presented in and described in the following sections.

7.5 DDSS Decision Model

The framework for the proposed DDSS is conceptualised as a *Decision Model*, which fits within existing AECO workflows as well as within other proposed or existing information model typologies: *Requirements Model* (Kiviniemi, 2005), *Design Model(s)*, *Production Model*, and *Asset Information Model* (Maintenance Model) (Table 7.2 and Figure 7.9). As used in this context, the term *decision model* is not revolutionary or new; it borrows its name from the work of others, such as Kam (2005), who have used the same term in their own work. However, while acknowledging that others used the same term in related contexts, the author argues the application of the term in the context of this thesis represents a unique artefact.

Table 7.2: Information model types

AECO Information Model Types	
Model Type	**Model Description**
Requirements Model	An information model which stores and updates project requirements over the course of a project's lifecycle, linking them to design models. (as conceptualised by (Kiviniemi, 2005))
Design Model(s)	A project information model created during the design phase of a project. May be referred to as a *Design Intent Model.*
Production Model(s)	A project information model created during the construction phase of a project. May be referred to as a *Virtual Construction Model.*
Asset Information Model (Maintenance model)	An asset information model (AIM) is a "structured repository of information needed for making decisions during the whole life cycle of a built environment asset. This includes the design and construction of new assets, refurbishment of existing assets, and the operation and maintenance of an asset" (ISO, 2018b).
Building Product Model	In the context of this thesis, a Building Product Model (BPM) is used to describe a generic building information model that includes 2D and 3D geometric representations of the physical and abstract information necessary to model and represent a building (Eastman, 1999, 2011). A building information model is often used in this context, but its use is avoided in this context to limit confusion with other meanings of the term BIM. At different stages of a project's lifecycle, a BPM may represent a Design Model, a Production Model, or an Asset Model.
Decision Model - Proposed	An information model which stores, and updates information related to design decisions (and their rationale) made during a project's life cycle, linking decisions to project requirements and a BPM.

The framework for the DDSS Decision Model links external data, information, and knowledge to project requirements and design decision-making processes in a manner described below. By linking design decision-making processes to project requirements and available support data, it enables AE designers to make more informed design decisions. It further enables pre- and post-design analytics by linking project criteria to design decisions.

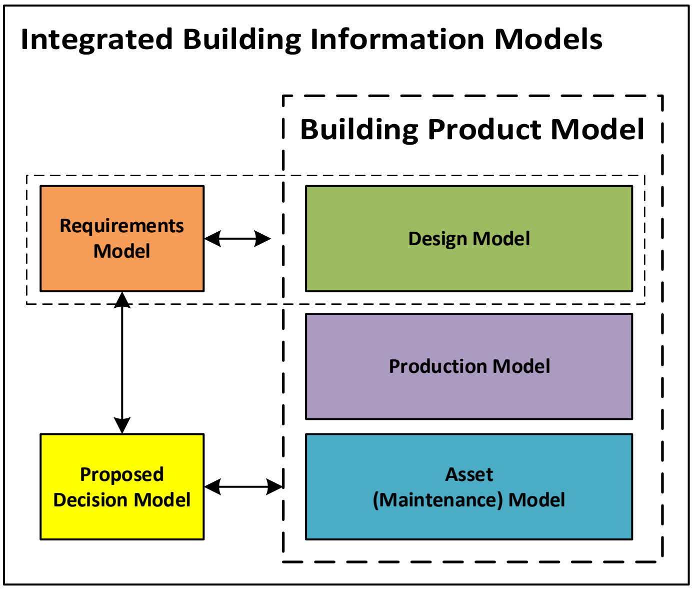


Figure 7.9: Integrated building information models

In proposing this DDSS, conceptualised as a Decision Model, this thesis refers to the concept of a *Requirements Model*, as presented by Kiviniemi (2005), that links project requirements and design decisions. According to Kiviniemi (2005):

> A link between Requirements and Design Objects can help designers to understand the interaction between Requirements and design solutions better. It also helps the project managers and Clients to manage the Requirements and to evaluate the design solutions compared to Requirements. (p. 4)

Kiviniemi (2005, p. 95) proposed an indirect link between the requirements model and a design model. A requirements model may also be integrated directly into a design model. The proposed DDSS Decision Model framework in this thesis builds on this conceptualisation of a linkage to the design model by adding a link to a new decision model (Figure 7.10).

(adapted from Kiviniemi 2005)

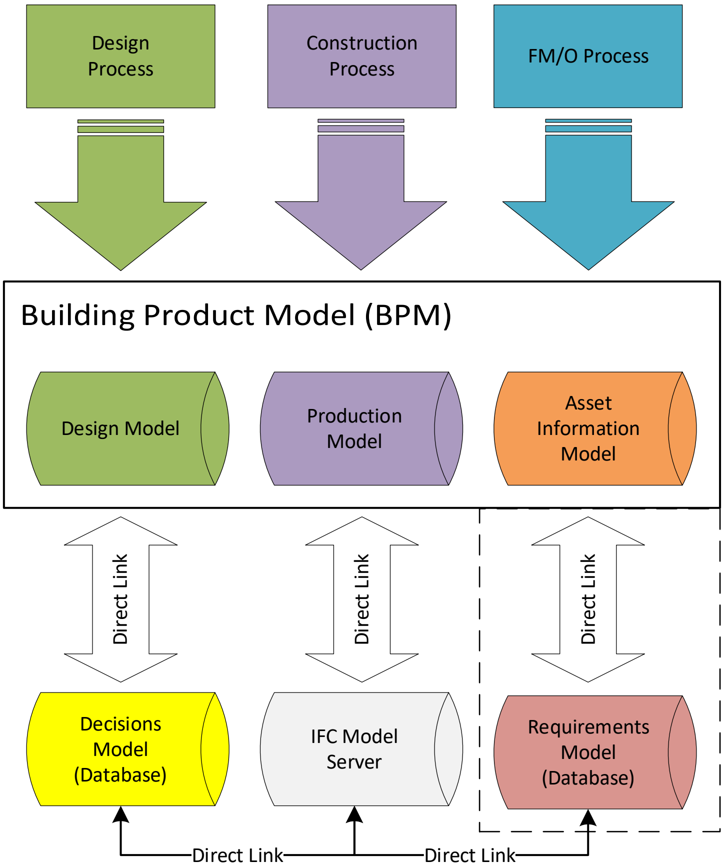


Figure 7.10: Decision model relationship to building product models

It should be noted Kiviniemi and Fischer (2004), Kiviniemi (2005), and others have created detailed descriptions for how a requirements model functions (Baldauf, Formoso, Tzortzopoulos, Miron, & Soliman-Junior, 2020; Jansson, Schade, & Olofsson, 2013). These descriptions may be useful and productive, but this author is not commenting on their specific legitimacy here. In the context of this thesis, the reference to a requirement model simply refers to a living information model of some kind in which project requirements are continually validated and updated over the course of a project and facility lifecycle. At its most basic level, a requirements model may simply be a text document or spreadsheet that is shared within a common data environment and is continually updated. Alternatively, it may be a highly structured database. Ultimately, what is most important in the context of this proposal is that the requirements model is continually validated and updated as necessary, that it is accessible, and there is a link to it.

7.6 DDSS – Decision Model Conceptual Diagram and Structure

The decision model described above acts as a DDSS (or a container) that establishes enhanced AE-design decisions by supporting the facilitation of FM/O information and knowledge within AE-design processes (Figure 7.11). While the DDSS does not directly enforce this integration, it houses sub-mechanisms that *nudge* AE-design teams and FM/O to increase their knowledge sharing and data transfer.

The DDSS– Decision Model contains multiple subsystems described as Design Decision Support Tools (DDSTs), including a data store; a series of checklists which link the AE-design team's information needs with FM/O data and information records; a DDST which links design decisions, project requirements, decision support data and rationale with building product model (BPM) objects; and decision and data trees which make design decisions with their related data visible in a non-model-based view. The DDSS and its subsystem DDSTs are represented in the diagram in Figure 7.12 and described in further detail below.

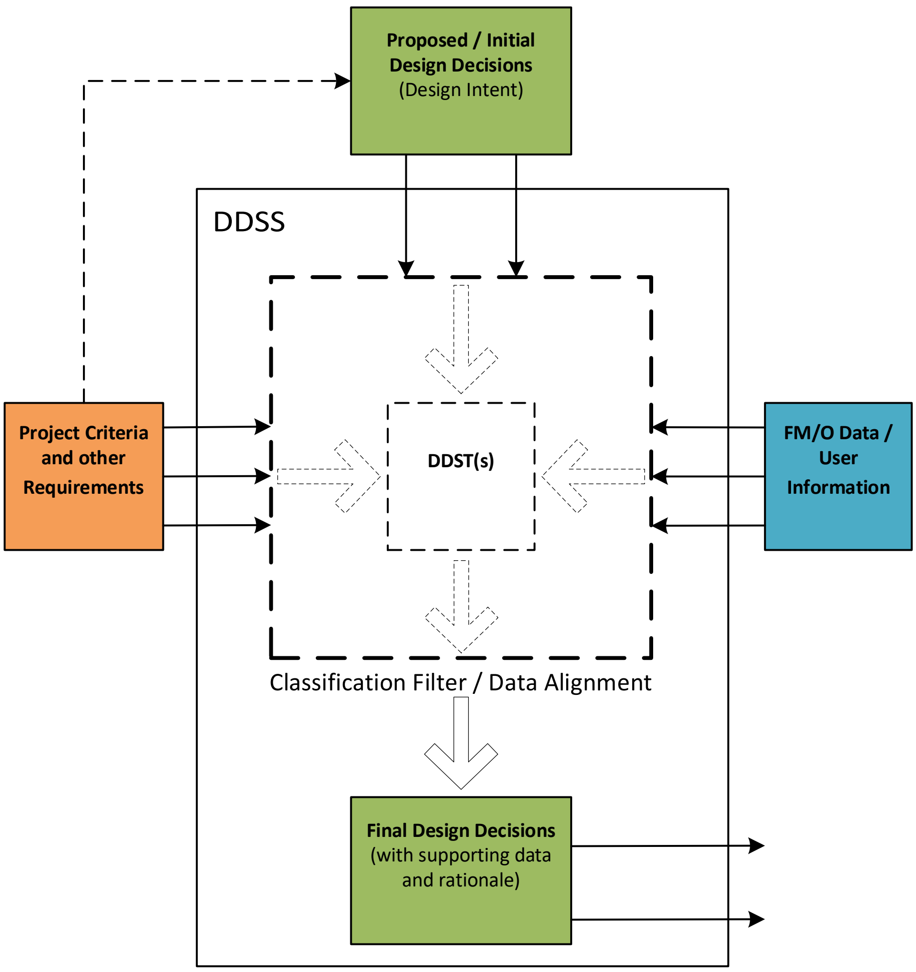


Figure 7.11: DDSS domain diagram

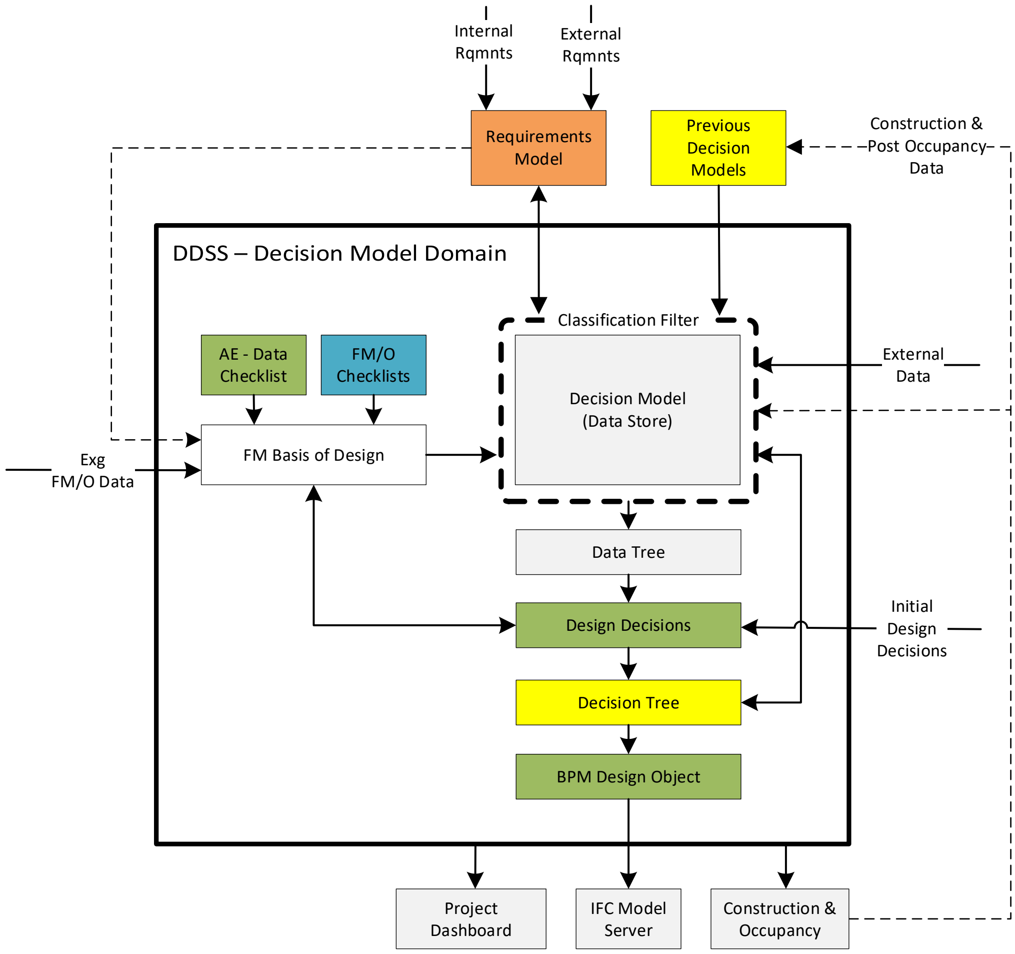


Figure 7.12: DDSS with DDSTs – project decision model conceptual diagram

7.6.1 DDST Data Classification Overview

The DDSS – Decision Model relies on a common classification system to link data, information, feedback, and knowledge from a range of sources, such as project requirements, FM/O related data, external data, or AE-design-related data. The DDSS uses a broad classification system which links these disparate data sources while allowing project specific classification systems to be maintained (such as OmniClass, Uniclass, IFC, et cetera.). The development of the Data Classification DDST is described in further detail in Section 7.8 below, but in the context of this diagram and its related narrative description, this classification system should be seen as a mechanism for linking disparate data types and sources within the DDSS – Decision Model.

7.6.2 DDST Data Checklists Overview

At, or near the beginning of a project, the DDSS asks both design teams and FM/O personnel to complete a checklist which itself acts as a DDST. For the design teams, this checklist creates an opportunity for them to consider the types of information they would like to receive from FM/O. For the FM/O teams, this checklist provides an opportunity for them to consider the types of data and information they store as well as what is important to them, and lessons learned. These checklists are then shared across disciplines and act as a *nudge* to get the disciplines to think of each other and consider each other's needs. The checklists are prepopulated with data types based on the classification system noted above but are also customisable to support a unique project or facility type. Based on these checklists, data and information is added to a data store and then classified according to the proposed classification system.

The checklists help start the design process by establishing a connection between AE-design and FM. They act as a nudge for the disciplines to be aware of each other's needs and resources. Decision science has shown it is possible to shift people's behaviour by simply informing them what other people are doing (Coleman, 1996; Thaler & Sunstein, 2009). Similarly, the concept of decision *priming* suggests that the act of hinting at an idea or concept can trigger an association that stimulates action. For example, decision science research shows that through the act of proctoring surveys to catalogue respondents' behaviour or knowledge, researchers can influence the same respondents' behaviour. That is, by measuring respondents' intentions, their conduct is likewise affected. According to Thaler and Sunstein (2009): "The 'mere-measurement effect' refers to the finding that when people are asked what they intend to do, they become more likely to act in accordance with their answers" (p. 71). Furthermore, this nudge can be accentuated by asking people when they intend to do something in addition to asking people what they intend to do. Such factors which influence people's behaviour have been referred to as *channel factors* by the psychologist Kurt Lewin (Lewin, 1947). Channel factors are small influences that facilitate or inhibit certain behaviours. Thaler and Sunstein (2009) broaden these findings to suggest that people can be *primed* into certain forms of behaviour by offering simple, and sometimes apparently irrelevant cues.

In the context of the DDSS, the DDST Data Checklists serve two primary purposes: 1) the checklists document FM/O related information available to AE-design teams; and 2) the data checklists act as channel factors which are intended to nudge AE-design teams and FM/O toward increased knowledge sharing. According to the decision science research noted above, the simple act of being aware of what information is available, or what information is desired, increases the likelihood information will be shared. In addition, the checklists also allow for a gated review process and establish a classification framework for other DDSTs and subcomponents of the DDSS – Decision Model.

The development of the Data Checklists as DDSTs, and the rationale behind them, their connection to findings from the previous chapter, and explanations of the logic behind their pre-population are further described and presented in Section 7.8.

7.6.3 DDSS Data Store Overview

The DDSS – Decision Model, includes a data store which houses the associated data and information. Files, data, and information are filtered and organised according to the DDST classification system, as well as any additional classification systems utilised on a project (such as MasterFormat). The data store is primarily populated with information and data from previous project decision models, a project's requirement model, external data associated with AE-design and construction, and FM/O related data.

The information that informs decisions can come from multiple sources (see Figure 7.3 above). While this study is focused on information that comes from facility management and operations, it could likewise come from building regulations, general knowledge, designers' experience, professional bodies of knowledge, reference standards, et cetera. AE-design teams are not forced to reference information and data within the data store; however, it is made available to them to use as they see fit and as necessary. The data store and associated DDSTs are intended to act as nudges which encourage AE-design teams to take advantage of the data store to inform design decision-making processes.

A further discussion of the data store is presented in Section 7.8.4; however, the development of a fully functioning data store is beyond the scope of this thesis and is presented in concept only. This represents an area of potential future research further discussed in Section 9.4.

7.6.4 BPM Decision Capture Overview

Within the DDSS – Decision Model, a subsystem DDST is proposed that enables design decisions and their rationale to be linked to project requirements and to support data or information from within the data store. It further classifies design decisions according to the proposed classification system (above) and attaches the design decisions and their supporting information to design objects within a BPM. Additionally, the BPM Decision Capture DDST allows exporting to an external IFC model viewer. This enables decisions to be visualised outside the confines of BIM authoring software, while still within the context of a BPM. A conceptual proposal for the development of the BPM Decision Capture DDST is described in further detail in Section 7.8.5.

7.6.5 DDST Data / Design Decision Tree Diagram Overview

Within the DDSS – Decision Model, data and design decision tree diagrams are used to 1) graphically visualise the data and information available and used within the proposed Decision Model, and 2) to graphically visualise, outside the context of a BPM, design decisions made and links to their supporting documentation. In this manner, it is possible for designers to easily see what data and information are available to them (related to a particular design decision) as organised according to the proposed classification system (Section 7.6.1 and 7.8.2). In addition, once a design decision has been made and documented, it is possible to graphically see each key decision and the rationale or supporting documentation which underpins that decision. Furthermore, design decisions can be viewed within the context of which project requirements they address, and inversely, project requirements can be used to filter what design decisions relate to each requirement.

The development of a fully functioning decision tree is beyond the scope of this thesis and is presented in concept only. This represents an area of future work discussed in Section 9.4.

7.7 DDSS – Decision Model Anticipated Benefits

The proposed DDSS – Decision Model and associated DDSTs can be seen as serving multiple purposes and as being beneficial to AECO processes in a variety of ways. These anticipated benefits are described as follows:

1. The DDSS framework allows project criteria and requirements to be linked to design decisions and Building Product Model (BPM) design objects. This facilitates a transparent design process and helps ensure project requirements are met while facilitating project evaluation and assessment.

2. It links project criteria and requirements to design decision rationale, which is likewise linked to BPM design objects. Linking decision rationale to project requirements additionally ensures project requirements are met and facilitates evaluation and assessment.
    a. As project requirements are revised and revisited over a project's life, any changes to the requirements can be flagged within the DDSS and DDSTs. Any design decisions and their rationale that are related to a changed requirement can be highlighted in both the design decision tree diagram and BPM. This allows any impacted design decisions to be revisited to confirm if they still make sense considering the requirement change(s).
3. The act of completing the data checklists makes AE-design teams more aware of FM/O knowledge resources. It similarly makes FM/O teams more aware of what they have to offer and what they may want addressed within a project. Furthermore, by having the checklists reviewed throughout the design process ongoing interaction is facilitated.
4. The simple act of asking AE designers to justify key design decisions and support those decisions with FM/O provided information, or external data, when appropriate, will make designers more aware of FM/O and nudges toward improved communication between disciplines. It further provides an easy mechanism for FM/O to review design decisions to ensure their needs are met.
5. The proposed DDSS facilitates improved substitution requests during bidding and negotiation and easier changes during occupancy by linking decision rationale and associated project requirements with design objects within the BPM and the associated design decision tree diagram. Linking the design objects to decision rationale and project requirements makes it easier to suggest or make changes, and to evaluate substitution requests.
6. Linking design objects and design decisions to project requirements and supporting information facilitates improved value engineering processes. It also facilitates value analysis processes (such as Choosing by Advantages (Suhr, 1999)), or other formal decision-making processes.
7. Linking project requirements, design decisions, and supporting information (such as who made which decisions and when, and rationale behind them) enables

project analytics, analysis, and auditing. It also facilitates the development of dashboards and similar mechanisms to visualise design performance.

7.8 DDST Detailed Development

Thus far, this chapter has presented a framework for a DDSS – Decision Model. It has also provided a conceptual overview for a series of subcomponents, referred to in this thesis as DDSTs (Design Decision Support Tools), which together constitute the full DDSS. It is beyond the scope of a single thesis to fully develop *each* of the proposed DDSTs which act as subcomponents for the proposed DDSS – Decision Model. However, the author proposes that select DDSTs are more important than others in that they provide the foundation for the others to be developed and function. To this end, the following section describes in further detail the development of a DDST Data Classification System and DDST Data Checklist(s). A proof-of-concept digital interface for the DDSS is also discussed, while formal development of the DDST Data Store, Decision Capture System, and Decision Tree System are proposed for future work (see Section 9.4).

7.8.1 DDST Validation Overview

The DDSS framework discussed above, and subsystem components (DDSTs) were validated through a series of validation interviews with practicing AE designers and FM professionals. These interviews were held throughout the development of DDSTs discussed below. Notes were taken and sketches and diagrams were made by the researcher and participant(s). In addition, interviews were recorded to provide for review. Participants were provided with an initial overview of the DDSS described above and then presented with the proposed DDSTs. Their feedback was documented and where appropriate incorporated into the proposed DDSS and DDSTs. In this manner, these meetings are used to validate the proposal.

In any research project, the researcher is left with a range of editorial decisions regarding how to present the research. The presentation of the following DDSTs, their development, refinement, and their validation, presents such an editorial decision in this research project. Because the following DDSTs evolved over the course of their development through validation interviews with practicing professionals, it presents an editorial question as to how best to present them. Due to the space limitations of single thesis, the researcher has opted to present them in their current form rather than in multiple developmental stages. Where significant changes were made in their development based on validation feedback, these changes are noted and discussed. But, *before* and *after* (feedback) changes is generally not presented as the developmental process was fluid. Furthermore, feedback and validation are discussed throughout where appropriate with a broader overview of the validation effort discussed in the following chapter.

The author also had an editorial decision regarding how to present the DDSTs as part of a broader system. The author chose to present the DDSTs as individual components prior to discussing how they work together within the larger DDSS system. This contrasts with discussing how they specifically work together prior to discussing the details of individual components. Because each individual DDSTs can work on their own, independently of the larger DDSS, they are presented individually first. A discussion of how the DDSTs interface together to form a working prototype DDSS is presented in the following chapter.

7.8.2 DDST – Proposed Data Classification

The data analysis discussed in Chapters 5 and 6, and the literature review in Chapter 2, identified multiple barriers which hinder information and knowledge sharing between FM and AE-design. The author's review of the literature and data collected found that these barriers to AE-FM/O knowledge sharing can be categorised as stemming from 1) a lack of resources (including knowledge classification strategies), 2) a knowledge gap (including a lack of awareness, 3) the nature of the design process, or 4) a lack of priority or incentive. This thesis is primarily focused on addressing the first two. The lack of incentive is beyond the scope of this thesis and represents an area of potential future research (Section 9.4). However, it is anticipated that by addressing the lack of awareness and classification, within the fundamental nature of the building design process, barriers to knowledge transfer will be reduced, thereby addressing lack of incentive-related barriers.

As seen in the semi-structured interview phase of the research, the lack of appropriate classification and lack of awareness represent circular issues that cannot be understood or addressed in isolation. For example, it is difficult to be aware of what information FM/O tracks that might be beneficial to AE-design if that information is not classified in a useable manner. Similarly, it is difficult to classify FM/O information that would benefit AE-design without being aware of what is available. They are therefore discussed briefly together here, but the development of their respective DDSTs is described individually.

Referring to Chapter 5's discussion of the semi-structured interviews, three interview exchanges that highlight the issue of classification and awareness are revisited. In the interview with I-1 FM, the interviewee lamented that they, FM/O, have information that would be beneficial to AE-design if they would only ask for it:

> [**Interviewer:** In your experience based on past projects, how would you describe the availability of FM/O data to the design team?]
>
> **I-1 FM:** For us? All you have to do is ask, and we'll give it to you. I don't know about other places, but since we're a public university, we're pretty [open].
>
> [**Interviewer**: But they have to ask?]
>
> **I-1 FM:** They do have to ask. They can't just [assume we'll throw it at them].
>
> [**Interviewer:** Do they ask?]
>
> **I-1 FM:** Not as much as I wish they did. I feel like that would have saved a lot of [trouble], even just little things [if they asked].

Throughout the interviews, it was thematically evident AE respondents would like to receive information from FM/O, but they could not pinpoint what information they wanted, nor were they generally aware of what information FM/O might have or track. The solution was to want *everything,* or "spreadsheets for days" as voiced by I-4 AE.

> [**Interviewer:** …what data or related information would you like to receive from a facility manager or facility operations if any?]
>
> **I-3 FMAE:** I think […] as much information as possible that's relevant to, […], the process of architecture and you know, kind of the design-related aspects of it…

Unfortunately, the transfer of all available data and information from FM/O to AE-design is unrealistic, if not impossible. This can be seen in a representational anecdote shared by an FM during a pilot interview. This FM works for a public institution of higher education with approximately 15,000 students. At the time of the interview, the FM was working with an AEC team on a renovation project who requested a specific piece of information from the FM. The information took over three hours to find because the institution stores their FM/O information on a single share drive which was reportedly difficult to navigate. This scenario, considering the FM understood the shared drive and how its information was structured, but still needed three hours to find the piece of important information, anecdotally suggests the limitations and impracticality of sharing “as much information as possible that’s relevant to the process of architecture…” unless it is properly classified. For both FM/O to reasonably share relevant information and knowledge, and for AE-design to appropriately request such information, it is necessary that effective mechanisms be put into place to classify related information *and* be able to request it.

7.8.2.1 DDST – Proposed Data Classification

A range of classification systems and data exchange schemas exist within the AECO domain (Table 7.3); however, the data analysis associated with the online questionnaire (Chapter 6) suggests these classification systems are not universally understood or broadly used. This finding reflects the view by Lützkendorf et al. (2005) who suggest various forms of building requirement definitions have been developed, but there is no commonly accepted standard.

While existing classification systems describe building elements, requirement types, or categorise building-related information, they are limited in their ability to classify data and information that would be beneficial for design decisions. The problem with these classification systems, when related to the proposed DDSS-Decision Model and its goal of improving information and knowledge sharing between FM/O and AE-design, is that they are too specific, too broad, or unable to function at multiple scales. Furthermore, they are unable to connect the information FMs track (FM’s Body of Knowledge (BOK)) with the types of key decisions made by an AE-design team during design decision-making processes – they classify objects but not knowledge. Additionally, a given category of FM/O data or information may pertain to a range of design decisions and project requirements and therefore needs to be categorised in multiple ways.

Table 7.3: Overview of common built environment classification systems

Various forms of built environment classification systems and data exchange schemas		
Classification System		**Overview of systems and their focus**
Classification Systems	**Omni Class**	"…is a means of organising and retrieving information specifically designed for the construction industry." "OmniClass is designed to provide a standardised basis for classifying information created and used by the North American architectural, engineering and construction (AEC) industry, throughout the full facility life cycle from conception to demolition or reuse, and encompassing all of the different types of construction that make up the built environment. OmniClass is intended to be the means for organising, sorting, and retrieving information and deriving relational computer applications" (CSI, 2017).
	MasterFormat	"MasterFormat provides an "organisational framework for the written and graphical instructions for the complete construction of commercial buildings… It is the standard for arranging construction project manuals containing bidding requirements, contracting requirements and specifications. Architects, builders, and contractors use it when drawing up plans, and facilities managers use it when operating buildings. With its 2004 expansion, MasterFormat incorporated computer networks, telecommunications and facilities management categories." "Since the release of the 2004 edition, the focus of MasterFormat has been to go beyond the design phase and to include the entire lifecycle of the building - from design to procurement to construction to technological integration and beyond. By having a uniform method of documentation, it should be easier for facility management professionals to access and understand information that has been provided in a common language for different elements of the building" (MasterFormat, 2021).
	UniClass 2015	"Uniclass is a voluntary classification system for the construction industry that can be used for organising information throughout all aspects of the design and construction process, including office management, project information, cost information, specifications, and so on" (Uniclass, 2020).
Data Exchange Schema	**IFC** (Industry Foundation Class)	"… an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well. The Industry Foundation Classes specify a data schema and an exchange file format structure" (ISO, 2018a)
	COBie (Construction-Operations Building Information Exchange)	"COBie is an information exchange specification for the life-cycle capture and delivery of information needed by facility managers. COBie can be viewed in design, construction, and maintenance software as well as in simple spreadsheets. This versatility allows COBie to be used on all projects regardless of size and technological sophistication" (NBIMS-US, 2015).

Because the proposed DDSS (Decision Model and associated DDSTs) seeks, in part, to link project requirements with FM/O data, and AE-design decisions (which are additionally linked to design objects within a BPM), a classification system that bridges the gap between these domains is proposed. That is to say, a classification system is proposed that can connect key design decisions with BPM design objects, project requirements, and FM/O information and knowledge (Figure 7.13). The classification systems seek to link a range of external data sources and types, but the focus of this thesis is on FM information and knowledge. The linking of other sources represents an area of future research (Section 9.4). The following section discusses the development of a DDST that addresses the lack of an appropriate classification barrier discussed above. This establishes the basis for the next section, which describes the development of a DDST that addresses the lack of awareness barrier.

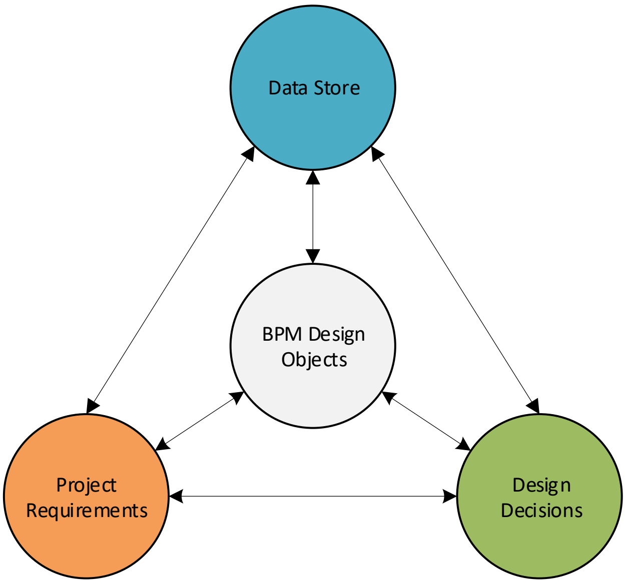


Figure 7.13: Relationship of decisions, requirements, design objects, and data store

The analysis of topics from the semi-structured interviews and online questionnaire related to questions asking about what information would be most helpful to share with AE-design from FM/O led the researcher to initially develop a classification made up of 10 proposed thematic categories.

1. **Capabilities** (Knowledge / skill of FM/O staff)
2. **Cost** (Cost implications)
3. **Design** (Design standards)
4. **Energy and Utilities** (Energy and non-energy utility use and consumption)
5. **Equipment and Systems** (Existing equipment / systems)
6. **Materials** (Existing materials)
7. **O&M** (Operations and maintenance procedures)
8. **Risk** (Risk mitigation)
9. **Space** (Space use)
10. **User Experience** (User or occupant experiences)

To refine and validate these initial classification categories, they were presented to 32 practicing AEC/FM professionals through an online questionnaire (Appendix H and I) and 10 individual AE and FM professionals through the previously discussed validation interviews. They were then updated based on feedback from the questionnaire and validation interviews. The categories were validated through both the additional online questionnaire and in person meetings because they are important in the development of the proposed classification system for FM/O - AE shared information, and knowledge. In this capacity, they form the foundation for the remaining DDSTs and the broader DDSS itself. Through these meetings and follow-up questionnaire, these initial categories were refined to the classification systems presented in Table 7.4.

Table 7.4: Proposed DDST knowledge classification categories

DDSS Classification Categories (refined post validation measures)		
	Category	**Description**
1	**Building Systems and Equipment** (Existing buildings and/or specialty systems and equipment, etc.)	Information related to the type, quantity, and location of existing equipment and systems. This includes what information is tracked for equipment and systems, preventative maintenance procedures, predictive maintenance procedures, etc. • Examples: specifications, location, maintenance logs of equipment or systems, etc.
2	**Construction Methods and Materials** (Commonly used construction materials or methods, etc.)	Information related to the common use of particular or specific materials in similar facilities, or other facilities owned or operated by the client or FM/O team. May also refer to existing stock (attic stock) on hand. • Examples: commonly used materials, or materials stockpiled.
3	**Design Standards and Specifications** (Internal standards or performance specifications, etc.)	Information related to existing design standards or performance specs in similar facilities, or other facilities operated by the client or FM/O team. • Examples: Colour, material, performance standards.
4	**Energy and Utilities** (Energy and non-energy utility use and consumption, etc.)	Information related to energy use and efficiency measures in similar facilities, or other facilities owned or operated by the client or FM/O team. • Examples: energy and utility consumption and unit costs.
5	**Life Cycle Costs** (Life cycle or general cost implications)	Information related to general FM/O costs from similar facilities, or other facilities owned or operated by the client or FM/O team. • Examples: maintenance or operational unit costs.
6	**Operations and Maintenance Procedures and Capabilities** (Standard procedures, capabilities, or limitations, etc.)	Information related to the knowledge and skill set of FM/O teams, including technicians. Includes information related to institutional capabilities with regards to operation and maintenance. • Examples: janitorial cleaning frequency, maintenance schedules, training.
7	**Risk - Health, Safety, and Security** (Mitigation measures or related incidents, etc.)	Information related to risk mitigation strategies and procedures in similar facilities, or other facilities owned or operated by the client or FM/O team. • Examples: incident reports, security measures, common risks, security requirements.
8	**Space Utilisation** (Space utilisation rates, etc.)	Information related to how spaces are used in similar facilities, or other facilities owned or operated by the client or FM/O team. • Examples: space utilisation rates, alternative space use, specific space needs.
9	**Sustainability** (Internal sustainability measures, standards, operating procedures, etc.)	Information related to existing or desired sustainability practices and internal requirements. • Examples: implemented standards, limitations due to staff skill sets or other resources, goals, and requirements.
10	**User or Occupant Experience** (User or occupancy experiences, satisfaction, etc.)	Information related to user or occupant experiences in similar facilities, or other facilities owned or operated by the client or FM/O team. • Examples: employee productivity or user satisfaction surveys, sick days.

During the ongoing DDSS validation process and testing of the digital DDST proof of concept prototype discussed in the following chapter, respondents were asked to provide specific examples of information related to these proposed categories. Select examples are provided in Table 7.5 to provide additional insight regarding how this classification system might function, with further discussion provided in Chapter 8.

Table 7.5: DDST classification system examples

DDST Classification System Categories – Respondent Examples
1. Building Systems and Equipment *(Existing buildings and/or specialty systems and equipment, etc.)*
Direct-Indirect evaporative coolers have worked well for us in the past, but their size, when placed on the roof, have caused repeated complaints and comments from building users. When/if used, they should be screened properly.
2. Construction Methods and Materials *(Commonly used construction materials or methods, etc.)*
Example: Ballasted roofs are difficult for us to maintain due to the prevalence of needle losing trees in the area around the site that regularly fill the ballast material with dead needles. This regularly creates maintenance issues on existing facilities.
3. Design Standards and Specifications *(Internal standards or performance specifications, etc.)*
Exterior and facade materials are required to be integrally coloured to reduce maintenance costs when the material is damaged.
4. Energy and Utilities (Energy and non-energy utility use and consumption, etc.)
Buildings on campus are not individually metered for water or electricity. This makes it impossible to measure the impact or ROI of energy/utility saving measures.
5. Life Cycle Costs *(Life cycle or general cost implications)*
Over time, the greatest maintenance cost in our facilities is related to floor cleaning. All floor materials must be easily cleaned with standard cleaning supplies and techniques.
6. Operations and Maintenance Procedures and Capabilities *(Standard procedures, capabilities, or limitations, etc.)*
We do not have access to lifts that extend over 15’ high. Materials and equipment that regularly needs service cannot easily be maintained if more than 15’ above a stable work surface or if not accessible by a mezzanine or roof
7. Risk - Health, Safety, and Security (Mitigation measures or related incidents, etc.)
We have had a significant number of safety incidences at entries with roll-up floor mats vs entrances with recessed walk-off mats. The roll-up mats are not maintained frequently enough and tend to roll-up on the edges causing trip hazards.
8. Space Utilisation *(Space utilisation rates, etc.)*
Conference rooms and study areas on the north side of university buildings are rarely used – as evident by booking records and the lack of required janitorial work in these rooms.
9. Sustainability *(Internal sustainability measures, standards, operating procedures, etc.)*
Shading devices prevent routine maintenance of windows and facade material.
10. User or Occupant Experience *(User or occupancy experiences, satisfaction, etc.)*
Visitors complain of getting lost within the building. Additionally, they regularly report having difficulties finding the entrance.

As discussed above, multiple classification systems are used in the AECO industry. These systems were looked to for their potential to be used in the proposed DDSS. However, in the context of this research, these existing systems were deemed inappropriate as they classify systems or objects, but not knowledge related to building systems. Furthermore, data collected in the interview and questionnaire phases of this research found widespread lack of familiarity with existing classification systems. Due to these factors, this research proposes a new classification system to connect design decisions to FM/O data and knowledge. Table 7.6 compares this proposed DDST classification system to selected existing systems. The DDST classification system described in this section provides the foundation for the DDSS itself and all remaining DDSTs. To this end, this classification systems is seen as an essential part of this research project and is presented as a new and effective method to improve knowledge sharing between FM/O and AE-design teams.

Table 7.6: Proposed DDST classification system compared to existing systems

Potential Classification Categories Compared								
IFC Hierarchy	**COBie**	**Requirements Model (Based on IFC hierarchy) (Kiviniemi, 2005)**	**Performance Requirements (Lützkendorf et al., 2005)**	**IFMA Core Competencies (presented as a classification system)**	**Whole Building Design Guide**	**MasterFormat***	**UniClass 2015**	**Proposed DDSS Categories**
Project	Component	Spatial System	Functional Performance	Communication	Accessibility	Specifications	Co - Complexes	**Building Systems and Equipment**
Site	Types	Indoor Conditions	Technical Performance	Emergency Preparedness and Business Continuity	Aesthetics	Facility Construction	En - Entities	**Construction Methods and Materials**
Building	Spaces	Safety	Economic Performance	Environmental Stewardship and Sustainability	Cost-Effective	Facility Services	Ac - Activities	**Design Standards and Specifications**
Building Stories	Zones	Comfort and Aesthetics	Environmental Performance	Finance and Business	Functional / operational	Site and Infrastructure	SL - Spaces/ locations	**Energy and Utilities**
Spaces	Facilities	Environmental Pressure	Social Performance	Human Factors	Historic Preservation (where applicable)	Process Equipment	EF - Elements/ functions	**Life Cycle Costs**
Systems	Floors	Location	Process Performance	Leadership and Strategy	Productivity		Ss - Systems	**Operations and Maintenance Procedures and Capabilities**
-Building Envelope	Systems	Service Life		Operations and Maintenance	Security / Safety		Pr - Products	**Risk - Health, Safety, and Security**
-Circulation	Contacts	Adaptability		Project Management			TE - Tools and Equipment	**Space Utilisation**
-System	Documents	Codes		Quality			PM - Project management	**Sustainability**
-Structural System	Attributes			Real Estate and Property Management			Zz- CAD	**User or Occupant Experience**
-Technical Systems	Connections			Technology			FI - Form of information	
	Assemblies						Ro - Roles	

* MasterFormat consists of 50 divisions and several subsections. Only Subgroups are indicated here.

7.8.3 Proposed DDST Checklists

Section 7.6.2 above describes the conceptual and theoretical underpinnings of the proposed DDST Data Checklists. This section now presents the checklists themselves and describes their function in more detail. As discussed previously, these checklists are intended to act as nudges which prompt AE-design teams and FM/O to improve knowledge sharing. The checklists create a connection between AE-design and FM at the start of the design process.

These checklists are presented in the tables below (Table 7.8, Table 7.9, Table 7.10, and Table 7.11). As presented, the checklists are conceptualised as digital forms which can be filled out on a computer and linked to a project database or data warehouse, however, in the form presented, they can also be printed out and filled in by hand for future digitisation. This possibility is presented as a method for addressing potential technology gaps, or lack of necessary digital skills within AE or FM/O teams. The checklists are also presented in this form to aid in their presentation and discussion within the context of a written thesis. Ultimately it is the intention that these checklists would form the foundation of a cloud-based app that acts as the DDSS described in Section 7.6. A discussion of a prototype for this application and associated digitalisation of these checklists as online forms is presented in Chapter 8. However, in this section, the tables below are presented to frame their presentation and discussion.

As presented in Section 7.6.2, at the beginning of a project, both design teams and FM/O personnel are asked to complete a series of checklists. For the design teams, this checklist creates an opportunity for them to consider the types of data and information they would like to receive from FM/O. For the FM/O teams, this checklist provides an opportunity for them to consider the types of data and information they store as well as what is important to them, and lessons learned. These checklists are then shared across disciplines and act as a nudge to get the disciplines to think of each other and to consider each other's needs. The checklists are prepopulated with data types based on the classification system described above but are also customisable to support a unique project or facility type. Based on these checklists, data and information is added to the data store and then classified according to the proposed classification system. This process is not linear, as activities within each discipline may be completed simultaneously, but for the sake of a written thesis, these activities are necessarily presented in a sequential manner. However, efforts are made to describe how and where activities overlap. Furthermore, Figure 7.15 is presented at the end of this section to visually describe the process herein described in writing.

Each of the checklists (also referred to as forms) have commonalities which are briefly discussed prior to more detailed discussions of each form. In addition to being based on the DDST classification system presented above (Table 7.4), each form tracks general project information such as project number, type, phase, or occupancy type (Table 7.7). This information is tracked and inputted into a data store, thereby allowing for information and knowledge to be shared across projects and time frames. In addition, each form uses a common scoring system (1 – 4) to rate the perceived value of information and data. This is discussed in further detail with each form below.

Table 7.7: DDST checklists – typical project data

Example		
Project Number:		**Date:**
Project Title:		**Phase:**
Occupancy Type(s): (If Mixed, check all that apply)	☐ Mixed ☐ Assembly ☐ Business ☐ Educational ☐ Factory and Industrial ☐ High Hazard ☐ Institutional ☐ Mercantile ☐ Residential ☐ Storage ☐ Utility and Miscellaneous	
Primary Reviewer (Last, First):		
Discipline/Project Role:		
Form Instructions: Individual form instructions provided here. Please provide an anticipated value to the design process for each tracked category based on the following scale: **0) No Value, 1) Low Value, 2) Moderate Value, 3) High Value, and 4) Essential** The "Notes" box provided to the right can be used to provide clarification or additional comments as necessary.		

Table 7.8 (below) represents the first DDST checklist and is provided to FM/O teams (and or an owner) at the beginning of a design or refurbishment project. This form is primarily intended to document FM/O related data and information available to AE-design teams. However, it also serves to act as a *channel factor* to *nudge* AE-design teams and FM/O toward increased knowledge sharing by making AE-design teams aware of what information is available from FM/O. In addition, the checklists allow for a gated review process. In this form, FM/O teams identify which categories of information they track data for, how that data is tracked, the perceived value of that data or information (as perceived by the FM/O team), any notes related to the data and being information tracked, and any file types for how the data or information is tracked. This information is provided to the AE-design teams and added to the data store.

Table 7.8: FM/O data tracking checklist

FM/O Data Tracking Checklist			
Project Number:		**Date:**	
Project Title:		**Phase:**	
Occupancy Type(s): (If Mixed, check all that apply)	☐ Mixed ☐ Assembly ☐ Business ☐ Educational ☐ Factory and Industrial ☐ High Hazard ☐ Institutional ☐ Mercantile ☐ Residential ☐ Storage ☐ Utility and Miscellaneous		
Primary Reviewer (Last, First):			
Discipline/Project Role:			

Form Instructions: Please identify in the boxes below in which areas you currently track facility management / operations and maintenance data. Please also identify in what form the tracked data is kept. Detailed description of each data category is included on the reverse side of this page. Data may be documented in multiple categories.

Please provide an anticipated value to the design process for each tracked category based on the following scale:
0) No Value, 1) Low Value, 2) Moderate Value, 3) High Value, and 4) Essential

The "Notes" box provided to the right can be used to provide clarification or additional comments as necessary.

Knowledge Category		Tracking		Data/File Types		Value (1-4)	Notes	Files
Ex.	**Capabilities** *(Knowledge/skill of FM/O staff)*	☐	*Yes*	*Text*	*(.txt, .rtf, .doc, etc.)*	*3*	*This is not tracked per se, other than through managers general awareness, but we do have specific limitations that could impact design.*	
		☐	*No*	*Data*	*(.xml, .csv, .tab, .xls, etc.)*	*3*		
		☐	*Unknown*	*Other*	*(Notes, images, etc.)*			
1	**Capabilities** (Knowledge/skill of FM/O staff)	☐	Yes	Text	(.txt, .rtf, .doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
2	**Cost/Lifecycle** (Cost implications)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
3	**Design** (Design standards)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
4	**Energy and Utilities** (Utility use)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
5	**Equipment and Systems** (Existing equipment / systems)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
6	**Materials** (Existing materials)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
7	**O&M** (O&M procedures)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
8	**Risk/Safety** (Risk mitigation)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
9	**Space** (Space use)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			
10	**User Experience** (User/occupant experiences)	☐	Yes	Text	(.txt, .rtf, doc, etc.)			
		☐	No	Data	(.xml, .csv, .tab, .xls, etc.)			
		☐	Unknown	Other	(Notes, images, etc.)			

In addition to completing out the FM/O Data Tracking Checklist (Table 7.8) at the beginning of a project, FM/O teams (or owners) are asked to complete an FM/O lessons learned checklist (Table 7.9). This form askes FM/O teams to briefly describe any important considerations or lessons learned from FM/O which may pertain to the design of the associated project. They may also identify any items they think should be addressed in the associated project design.

Users are asked to categorise these items based on the provided knowledge categories. Additionally, as individual lessons learned, or project specific items, may pertain to multiple knowledge categories, users may cross-reference entries under multiple knowledge categories. Users are then asked to provide a perceived importance of each item, using the 1-4 rating scale used for each form. Finally, users are asked to identify if they have files that pertain to each inputted item, for example, photographs that might document the concern or lesson learned, utility bills, or reports.

This form performs three primary purposes. First, it provides AE teams with a list of lessons learned or concerns from the FM/O team that they can use to inform their design process. In and of itself, this acts as a nudge by helping the AE-design team be more aware of FM's knowledge base. Second, by assigning a value to each entry, it provides the foundation to develop an *FM Basis of Desig*n that can be used to track design decisions over the life of a project. And third, by categorising the lessons learned, and any concerns which can later be linked to design decisions, entries can be uploaded to the data store thereby adding to the body of knowledge for reuse on other projects.

Congruent with the FM/O team completing the forms described above, the AE-design team is asked to complete an AE Data Wishlist (Table 7.10). The AE team is asked to complete the checklist based on their past experiences with specific project requirements. They are asked to identify from which knowledge areas they would like to receive related FM/O data and information. They are also asked to indicate their preferred format to receive the data or information and an anticipated value of the information (using the same 1 – 4 rating system).

This form is primarily used as a channel factor to get FM/O and AE talking together about what data, information, and knowledge they can share. It also acts to prompt the AE team to think about what would be useful to receive from the FM/O team.

Table 7.9: FM/O lessons learned checklist

FM/O Lessons Learned			
Project Number:		**Date:**	
Project Title:		**Phase:**	
Occupancy Type(s): (If Mixed, check all that apply)	☐ Mixed ☐ Assembly ☐ Business ☐ Educational ☐ Factory and Industrial ☐ High Hazard ☐ Institutional ☐ Mercantile ☐ Residential ☐ Storage ☐ Utility and Miscellaneous		
Primary Reviewer (Last, First):			
Discipline/Project Role:			

Form Instructions: In the lines below, please briefly describe any important considerations or lessons learned from FM/O which may pertain to the design of the associated project. That is to say, any items you think should be addressed in the associated project design. You may add additional lines, as necessary. Items may be documented in multiple categories.

Please provide an indicator of the importance of each factor below based on the following scale:

0) Not Important 1) Minimal Importance, 2) Moderately Important, 3) Very Important, and 4) Essential.

	Knowledge Category	Cross Referenced Categories	Importance (1-4)	Files
Ex.	***Example - Capabilities*** *(Knowledge/skill of FM/O staff)*			
0.1	*Exterior windows above 15' feet cannot be washed other than by hanging from the roof. Shading devices or shades that prevent access to windows from above will hinder maintenance.*	*3, 5, 7*	*2*	*.xls*
0.2	*Facility has limited access to lifts both on the interior and exterior. Mechanical equipment and lights that cannot be accessed directly or with a ladder will not be able to be serviced regularly.*	*3, 5, 8*	*3*	*.doc, .jpg*
1	**Capabilities** (Knowledge/skill of FM/O staff)			
1.1				
1.2				
2	**Cost** (Cost implications)			
2.1				
2.2				
3	**Design** (Design standards)			
3.1				
3.2				
4	**Energy and Utilities** (Utility use)			
4.1				
4.2				
5	**Equipment and Systems** (Existing equipment/systems)			
5.1				
5.2				
6	**Materials** (Existing materials)			
6.1				
6.2				
7	**O&M** (O&M procedures)			
7.1				
7.2				
8	**Risk/Safety** (Risk mitigation)			
8.1				
8.2				
9	**Space** (Space use)			
9.1				
9.2				
10	**User Experience** (User/occupant experiences)			
10.1				
10.2				

Table 7.10: AE information wish list

AE Data and Information Wishlist			
Project Number:		**Date:**	
Project Title:		**Phase:**	
Occupancy Type(s): (If Mixed, check all that apply)	☐ Mixed ☐ Assembly ☐ Business ☐ Educational ☐ Factory and Industrial ☐ High Hazard ☐ Institutional ☐ Mercantile ☐ Residential ☐ Storage ☐ Utility and Miscellaneous		
Primary Reviewer (Last, First):			
Discipline/Project Role:			

Form Instructions: Based on your experience and the project requirements, please identify which of the following knowledge areas you would like to receive related FM/operational and maintenance data. Please also indicate the preferred format in which you would ideally like to receive the data or information. The "notes" box provided to the right can be used to provide additional comments or clarification, as necessary.

Please provide an anticipated value to the design process for each tracked category based on the following scale:
0) No Value, 1) Low Value, 2) Moderate Value, 3) High Value, and 4) Essential.

	Knowledge Category	Desired	Data/File Types	Value (1-4)	Notes
Ex.	*Capabilities* *(Knowledge/skill of FM/O staff)*	☐ *Yes* ☐ *No* ☐ *Unsure*	☐ *Text (.txt, .rtf, .doc, etc.)* ☐ *Data (.xml, .csv, .tab, .xls, etc.)* ☐ *Other (Notes, images, etc.)* ☐ *Discuss in person*		
1	**Capabilities** (Knowledge/skill of FM/O staff)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, .doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
2	**Cost/Lifecycle** (Cost implications)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
3	**Design** (Design standards)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
4	**Energy and Utilities** (Utility use)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
5	**Equipment and Systems** (Existing equipment / systems)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
6	**Materials** (Existing materials)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
7	**O&M** (O&M procedures)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
8	**Risk/Safety** (Risk mitigation)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
9	**Space** (Space use)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		
10	**User Experience** (User/occupant experiences)	☐ Yes ☐ No ☐ Unsure	☐ Text (.txt, .rtf, doc, etc.) ☐ Data (.xml, .csv, .tab, .xls, etc.) ☐ Other (Notes, images, etc.) ☐ Discuss in person		

The completed forms provide the basis for a meeting between AE-design and FM/O. The channel factors and nudges of these checklists provide a foundation for improved information and knowledge sharing between the FM/O and AE teams. In the context of this research and DDSS, it is proposed that this meeting be called an *AE/FM Design Discovery Meeting*. During this meeting, the information gathered in the first three forms is used to develop an *FM Basis of Design* (Table 7.11). (This could also be thought of as a list of FM project considerations.)

The swim diagram presented in Figure 7.14 is used to visualise the concurrent processes described above related to the first three checklists. This diagram will be expanded and elaborated on below, but for now is used to clarify how the first three checklists lead to this point.

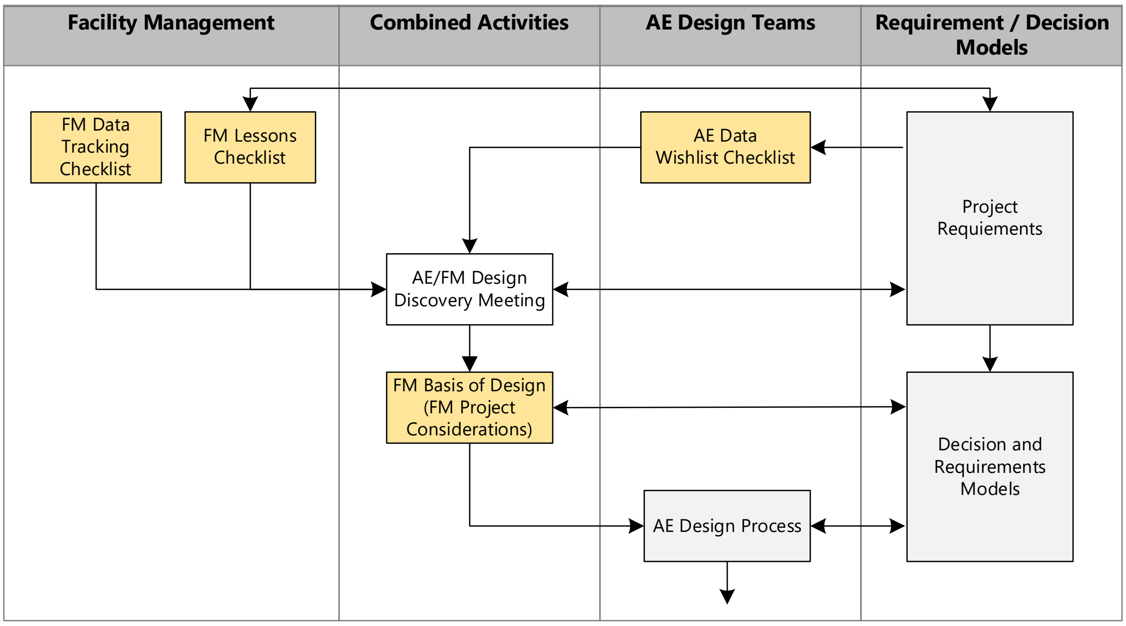


Figure 7.14: DDST checklists swim diagram - initial

Working from the information gathered in the previous checklists, the FM/O Basis of Design (Table 7.11) is used to document important considerations or lessons learned from FM/O which may pertain to the design of the associated project. It further highlights items the AE and FM/O teams think should be addressed in the associated project's design. In doing so, it further allows for a design decision audit, or tracking system that allows design decisions to be tied to specific project concerns, FM/O lessons learned, and data or information.

Table 7.11: FM/O basis of design checklist

FM/O Basis of Design

Project Number:	
Date:	
Project Title:	
Phase:	
Occupancy Type(s):	☐ Mixed ☐ Assembly ☐ Business ☐ Educational ☐ Factory and Industrial ☐ High Hazard ☐ Institutional ☐ Mercantile ☐ Residential ☐ Storage ☐ Utility and Miscellaneous
Primary Reviewer (Last, First):	
Discipline/Project Role:	

Form Instructions: In the lines below, please briefly describe any important considerations or lessons learned from FM/O which may pertain to the design of the associated project. That is to say, any items you think should be addressed in the associated project design. You may add additional lines as necessary. Basis of design and items may be documented in multiple categories.
Please provide an indicator of the importance each factor based on the following scale**: 0) No Value, 1) Low Value, 2) Moderate Value, 3) High Value, and 4) Essential.**
*Please evaluate design response to FM Basis of Design based on the following scale**: 0) Not Addressed 1) Somewhat 2) Moderately 3) Mostly and 4) Completely addresses listed FM/O concerns.**

	Knowledge Category	Score (1-4)	Referenced Categories	Design Phase Response	Project Phase	FM Audit of Design Response	Phase	Score (1-4) *	Files
Ex.	***Example - Capabilities*** *(Knowledge/skill of FM/O staff)*								
0.1	*Building elements and systems which require ongoing or routine maintenance will be provided direct access or be within 15' of work surfaces.*	*3*	*2.1,5.1*	*All lighting will be within 15' of work surfaces and all mechanical equipment will be directly accessible from a rooftop or mezzanine.*	*DD*	*Exterior windows above 15' feet cannot be washed other than by hanging from the roof. Exterior windows above the first floor cannot be washed because facility entrance gate prevents access of a lift.*	*PO*	*1*	*.jpg*
1	**Capabilities** (Knowledge/skill of FM/O staff)								
1.1									
2	**Cost** (Cost implications)								
2.1									
3	**Design** (Design standards)								
3.1									
4	**Energy and Utilities** (Utility use)								
4.1									
5	**Equipment and Systems** (Existing equipment/systems)								
5.1									
6	**Materials** (Existing materials)								
6.1									
7	**O&M** (O&M procedures)								
7.1									
8	**Risk/Safety** (Risk mitigation)								
8.1									
9	**Space** (Space use)								
9.1									
10	**User Experience** (User/occupant experiences)								
10.1									

In the FM/O Basis of Design checklist, AE and FM/Os work together to identify FM related project concerns and goals. These FM/O basis of design items are categorised, and cross referenced, based on the DDST knowledge categories. For each item, a value is assigned based on the project importance of that item (0 – 4, where 0 has no value and 4 is essential). Information collected in the form is then saved to a common data store for use throughout the project and subsequent projects. This FM/O basis of design can then be used to track individual design decisions and their effectiveness over the life cycle of a project.

Through the creation of a gated process, at each design phase, the criteria from the FM/O basis of design is reviewed, evaluated, and scored. At each gate, the AE-design team documents how they addressed each item from the checklist. The FM/O team then evaluates the design proposal, and the AE-design teams responses', and assign a value 1 – 4 for how well they feel the proposed response addresses the item (0 is not addressed and 4 completely addresses the listed concern). This process is repeated over the life of the design process as well as the life of the facility (Figure 7.15).

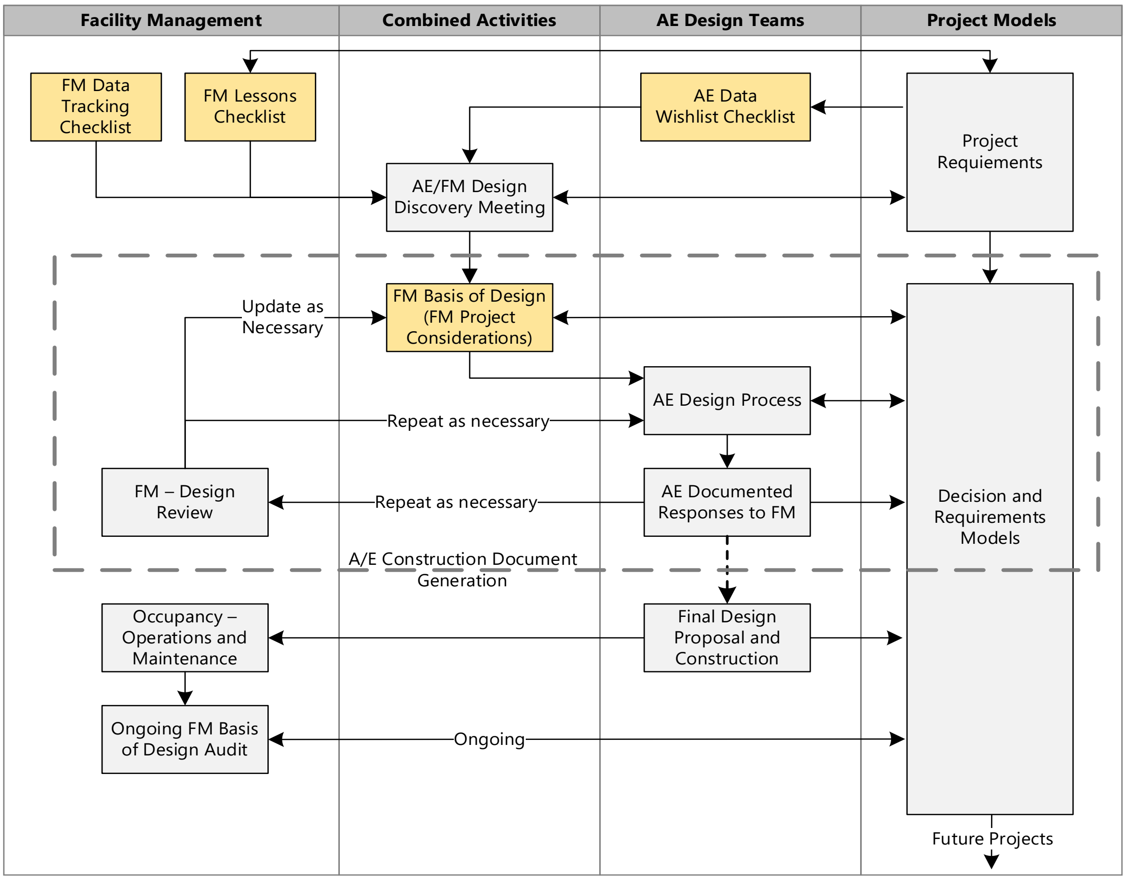


Figure 7.15: DDST checklists swim diagram - complete

This process serves multiple purposes in the context of this thesis and proposed DDSS. It allows design decisions to be tied to a project concern, requirement, or goal. It also allows a design decision to be linked to supporting documentation or evidence. These design decisions can then be tracked and audited over the life of a project and facility. When graphed visually, this would show where design decisions and project goals are converging, or not. Over the course of a project, these goals should be converging, and this process would show when they are not. When this information is stored in the data store, and tied to relevant knowledge categories, supporting data, and project concerns, it also allows for knowledge reuse on future projects.

7.8.4 DDST – Proposed Data Store

The development of a fully functioning data store is beyond the scope of this thesis and is presented in concept only. This represents an area of potential future research (Section 9.4). The proposed data store is intended to store and share FM knowledge, data, and information across a project's full life cycle, as well as between disparate projects. The data store is also intended to share information from the AE-design process to aid in the evaluation of design decisions throughout a project's full lifecycle. The DDST checklists discussed above feed information to this data store, but it would also be possible to feed information to the data store from the general body of knowledge to aid decision making. Likewise, the checklists discussed above, and data store itself, does not only have to be used in the context of a new project. The DDST checklists and data store could be used with existing facilities to track lessons learned to help improve day-to-day operations or to prepare for future projects.

An important aspect of the data store is that it be accessible to a range of users and for a range of project types. This would allow increased knowledge sharing across disciplines, clients, users, stakeholders, et cetera. For example, if a range of school districts utilised the DDSS, lessons learned could be shared across a broad range of users, thereby amplifying the ability of the proposed DDSS to improve design decisions. This would be useful for both users with a large project portfolio and users with a limited project portfolio. Users with large portfolios could use the system to track decisions, lessons learned, or project outcomes, while users with limited portfolios could share data, information, and knowledge within a pool of users. This would allow users to learn from each other and to share lessons learned. Users could also search for similar problems or potential solutions from other projects. It is recognised that this proposed use presents a range of privacy and intellectual property issues, however, the researcher is confident these issues can be worked out but are beyond the scope of this theses. However, this does present an area of potential future work (Section 9.4).

Figure 7.16 provides a conceptual diagram of how a *Decision Model* data store might be structured. Furthermore, Chapter 8 discusses how the proposed DDSS fits within a typical AE-design process. Chapter 8 also discusses a proof-of-concept web app which functions as the proposed Checklist DDST. The application building utility Zoho Creator (creator.zoho.com) is used to develop this proof-of-concept DDSS. Zoho Creator uses a combination of relational and key-value databases underneath; however, a range of data store and database types could develop to support the proposed DDSS.

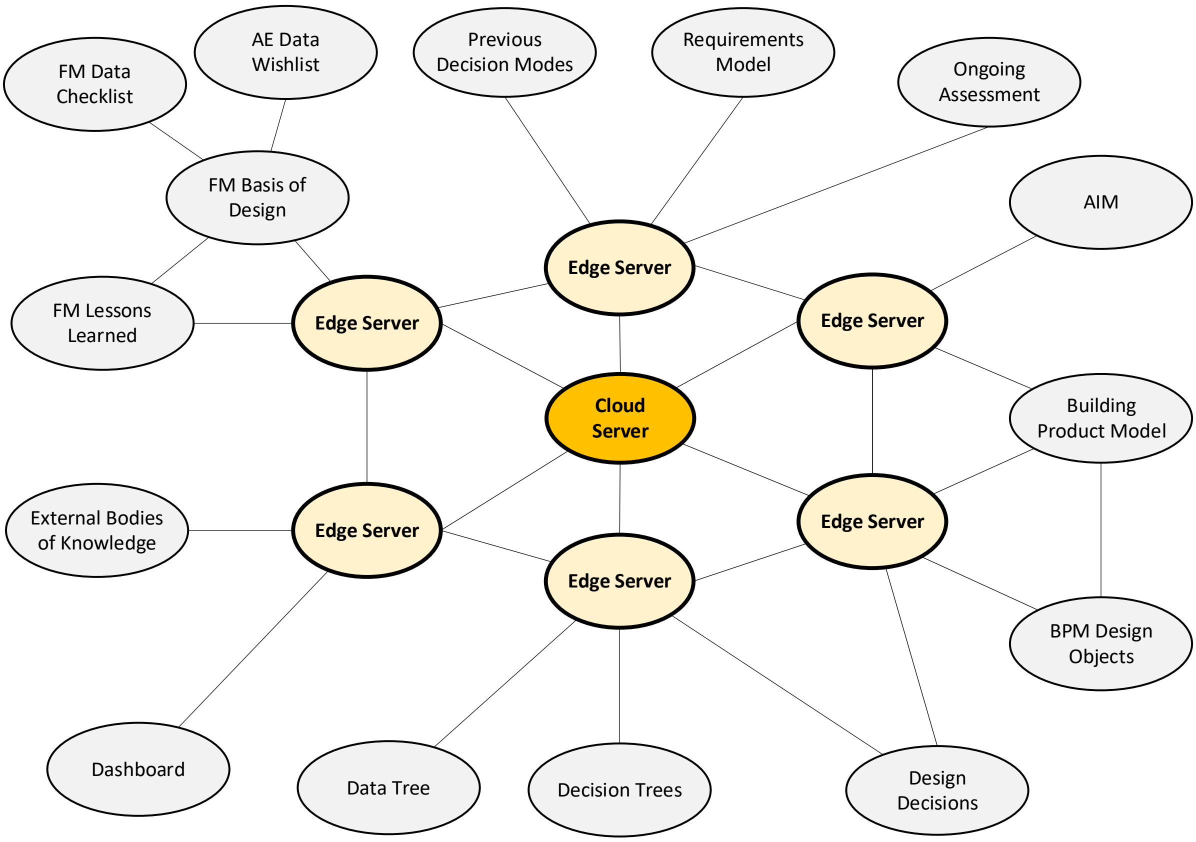


Figure 7.16: DDST decision model data store concept diagram

7.8.5 DDST – Proposed BPM Decision Capture

The development of a fully functioning BPM decision capture is beyond the scope of the thesis research aim and scope. Therefore, it is presented in concept only and represents an area of potential future development, as discussed in Section 9.4.

The proposed FM/O Basis of Design DDST checklist discussed in Section 7.8.2.1 links design decisions to the FM/O body of knowledge as well as other supporting information and data. It allows design decisions to be tracked and audited across a project's full lifecycle. Furthermore, through the proposed data store, it allows this auditing to be shared across projects and users thereby allowing lessons learned to be shared across projects and time frames. This decision tracking is searchable through the data store and can be visualised in a variety of methods. However, this DDST checklist and data store does not link design decisions, rationale, supporting documentation, auditing, et cetera to building product models (BPM) or asset information models (AIM). As BIM is increasingly used to develop and utilise BPMs and AIMs, the linking of design decisions, rationale, and auditing to a BPM or AIM is seen as an important aspect of future development.

For key project decisions, the proposed conceptual BPM decision capture DDST stores and attaches the following information to BPM design objects or systems impacted by the decision:

1. *When* the decision was made or changed;
2. *What* the decision entails;
3. *Why* the decision was made;
4. Details of the decision;
5. The decision's impact;
6. Other options considered;
7. Any other decisions changed by the decision;
8. Project criteria or requirements changed by the decision; and
9. Decision-making process used (for example, Choosing by Advantages (CBA) or Target Value Design (TVD)).

7.8.5.1 Potential DDSS Visualisation

Figure 7.17 and Figure 7.18 conceptualise how the proposed building product model (BPM) decision capture DDST may look within an external IFC model viewer. The proposed DDST enables design decisions and their rationale to be tied to BPM objects and linked to project requirements and supporting data or information from within the data store. It further classifies design decisions according to the proposed classification system (Section 7.8.2) and attaches the design decisions and their supporting information to design objects within the BPM. Additionally, the BPM Decision Capture DDST allows for exporting to an external IFC model viewer. This enables decisions to be visualised outside the confines of BIM authoring software, while still within the context of the BPM.

When viewed in an IFC viewer, the BPM can be filtered to show BPM objects or design elements driven by a project requirement or decision (Figure 7.17). Furthermore, individual BPM objects may be selected, or filtered, to show the decision rationale and process associated with that object. The information attached to the BPM is linked to the data store and continually updated as changes are made through the lifecycle of the project.

While the BPM decision capture DDST links decisions and their supporting data to the BPM in a three-dimensional, object-based manner, the DDST Data and Decision tree diagrams discussed in the following section (Section 7.8.6) similarly link decisions in a non-model, two-dimensional manner.

Decision ID: 20110157

Category	Description	BY
Decision Date	2019/11/08	WD, PL
Classification	Equipment and Systems, Materials	EC
Decision	Anti-static carpet and underlayment to be used map room	WD, PL
Details	Carpet and pad installed over concrete slab	EC
Impact	Increased installation cost, shorter lifecycle, increased usability	EC
Rationale	Hard surfaces will make room too loud	EC
Alternatives	Exposed concrete, hardwood floor, vinyl tile, ceramic tile	EC
Related Decis.	None	EC
Process Used	Choosing by Advantages	EC

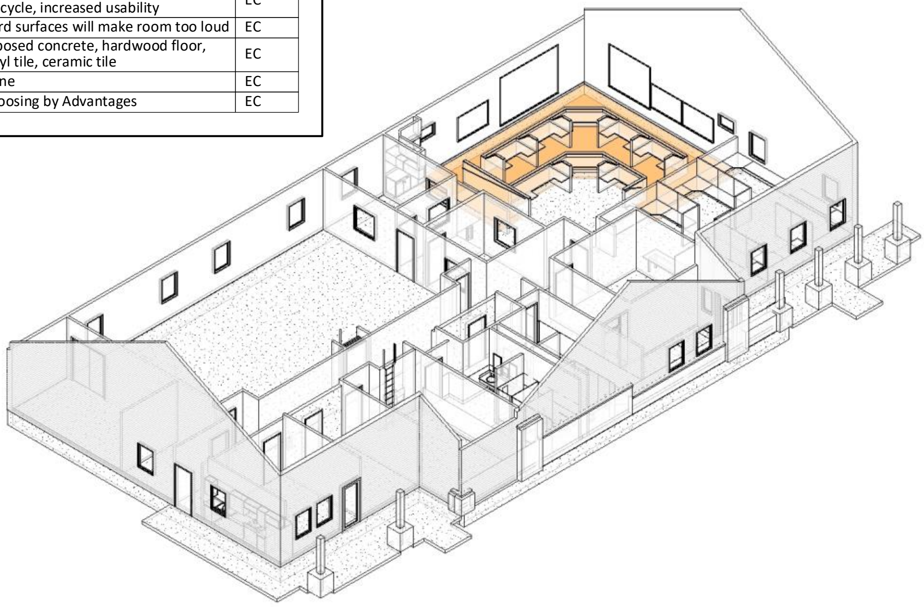


Figure 7.17: BPM decision capture DDST, Example 1

Decision ID: 20110158

Category	Description	BY
Decision Date	2019/12/06	WD, PL
Classification	Equipment and Systems, Materials	EC
Decision	2 hour rated walls in server room	WD, PL
Details	Walls to extend to ceiling and meet 2 hour rating requirments	EC
Impact	Increased installation cost	EC
Rationale	Critical equipment stored in room	EC
Alternatives	Standard wall construction, CMU	EC
Related Decis.	None	EC
Process Used	Choosing by Advantages	EC

Figure 7.18: BPM decision capture DDST, Example 2

7.8.6 DDST – Proposed Data / Design Decision Tree Diagrams

The development of a fully functioning data and design decision tree diagrams is beyond the scope of the thesis research question. Therefore, they are presented in concept only and represent an area of potential future research, discussed in Section 9.4.

Within the DDSS, data and design decision tree diagrams are used to 1) graphically visualise data and information available and used within the proposed Decision Model, and 2) to graphically visualise, outside the context of the BPM, design decisions made and links to their supporting documentation. In this manner, it is possible for designers to easily see what data and information are available to them (related to a particular design decision) as organised according to the proposed classification system (Section 7.6.1). In addition, once a design decision has been made and documented, it is possible to see each key decision and the rationale or supporting documentation which underpins that decision. Furthermore, design decisions can be viewed within the context of which project requirements they address, and inversely, project requirements can be used to filter what design decisions relate to each requirement.

In the context of the proposed DDSS, these proposed diagrams act as the visual link between the information collected in the DDST checklists (particularly the FM/O Basis of Design Checklist) and the BPM interface discussed above (Section 7.8.5). It is proposed that these diagrams would function as part of a cloud-based app and would be living documents, continuously updating over the life of a project.

The figures below (Figure 7.19, and Figure 7.21) provide a conceptual diagram for how the proposed data / design decision tree diagrams might function. Because these diagrams would require a functioning Data Store, which is beyond the scope of this thesis, these diagrams are presented conceptually. These diagrams are intended to function in an interactive manner that allows individual design decisions (or project requirements) to be selected and highlighted to reveal information associated with that decision, such as:

1. *When* the decision was made or changed;
2. *What* the decision entails;
3. *Why* the decision was made;

4. Details of the decision;
5. The decision's impact;
6. Other options considered;
7. Any other decisions changed by the decision;
8. Project criteria or requirements changed by the decision; and
9. Decision-making process used (for example, Choosing by Advantages (CBA) or Target Value Design (TVD)).

These interactive diagrams are intended to allow for decisions and supporting data to be tracked throughout a project's lifecycle, linking design decisions, and supporting data to the original project requirements. In this manner they function much like a 2d version of the proposed BPM capture discussed in Section 7.8.5. They further act as visual representations of Checklists discussed in Section 7.8.3 and Data Store discussed in Section 7.8.4.

Figure 7.19 (visualised as a tidytree) represents a visualisation of data available from FM (and other sources) for AE designers to use to aid their design decisions. It acts as a visual representation of the FM Data Checklist (Section 7.8.3) and general data store. Because the diagrams are presented through a cloud-based interface and are interactive, the AE-design team can expand each data classification category to reveal available data associated with that category. By clicking on each data node, descriptions of the available data are revealed, and the user can open any related files. This visualisation of the data store is intended to serve two primary functions: 1) it acts as a decision nudge helping designers be more aware of the data available to them to inform their decisions, and 2) it allows for a link to be made between decision supporting data and individual design decisions. These design decisions and data are then linked in design decision tree diagram(s) discussed below.

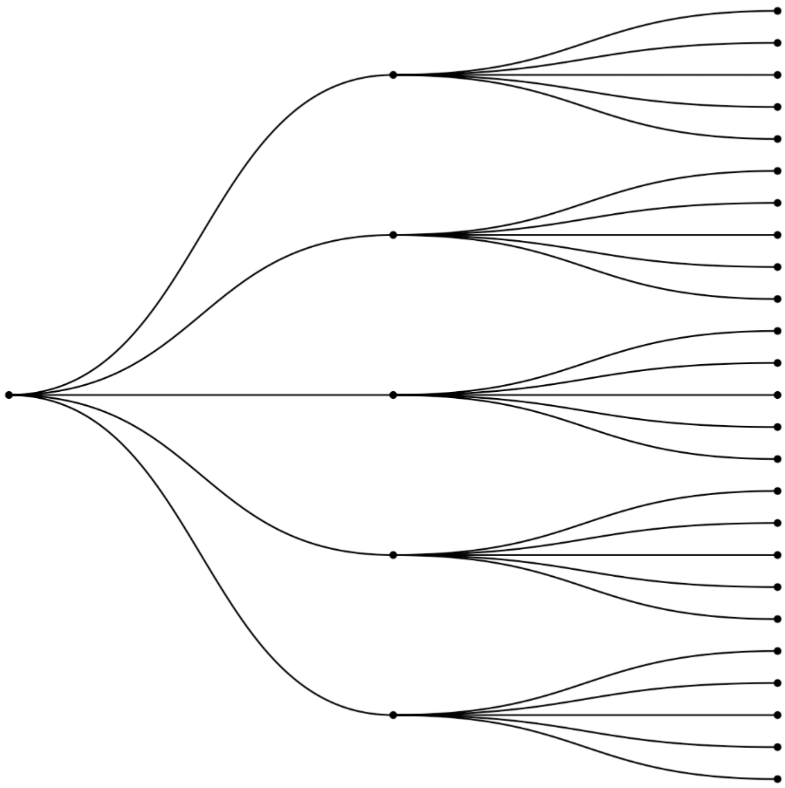


Figure 7.19: DDST decision support data – tree diagram

Figure 7.20 and Figure 7.21 represents a conceptualisation of the proposed design decision tree diagram. Over the course of a project, multiple decisions are made based on project requirements. These decisions are tracked and linked to related decisions and project requirements. At any point in time during a project, a key decision can be highlighted to reveal key information related to that decision, such as prior decisions that led to it, project requirements driving the decision, who made the decision, why the decision was made, or data and information supporting the decision.

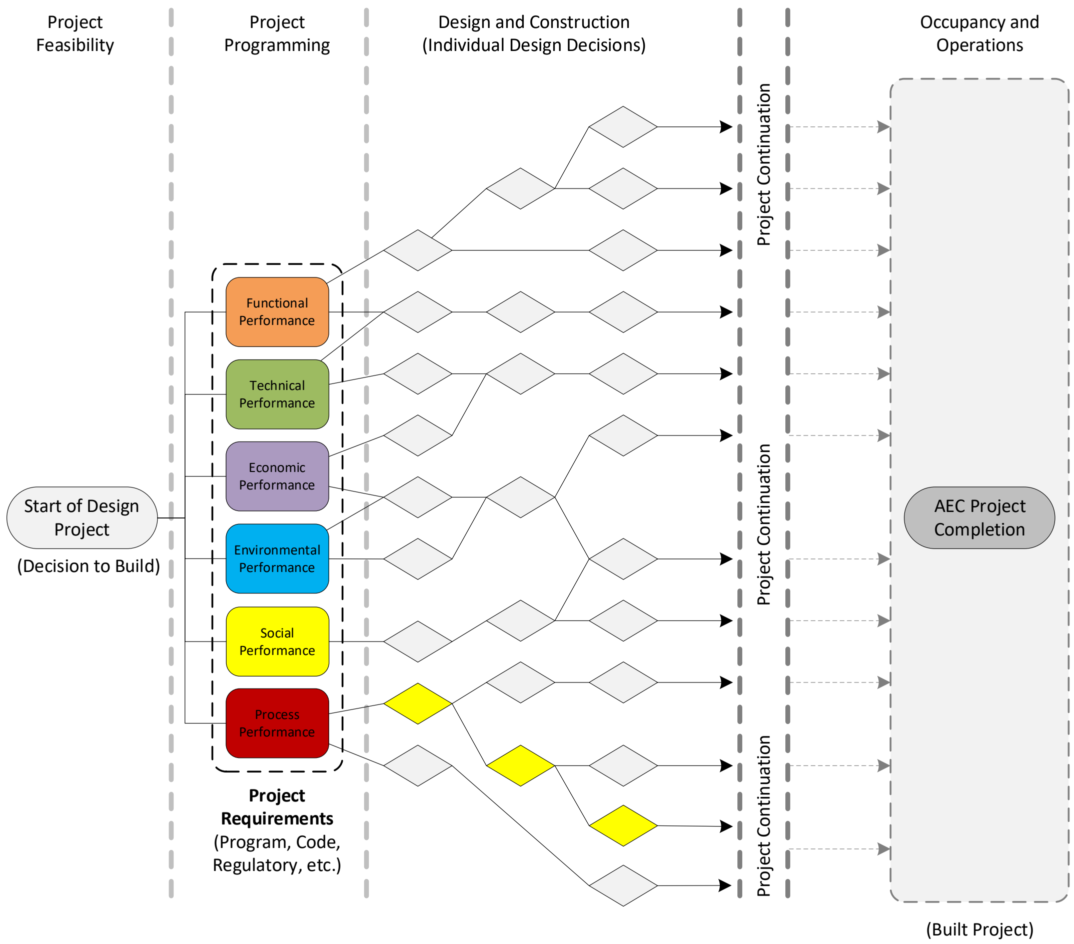


Figure 7.20: DDST key project decisions – tree diagram

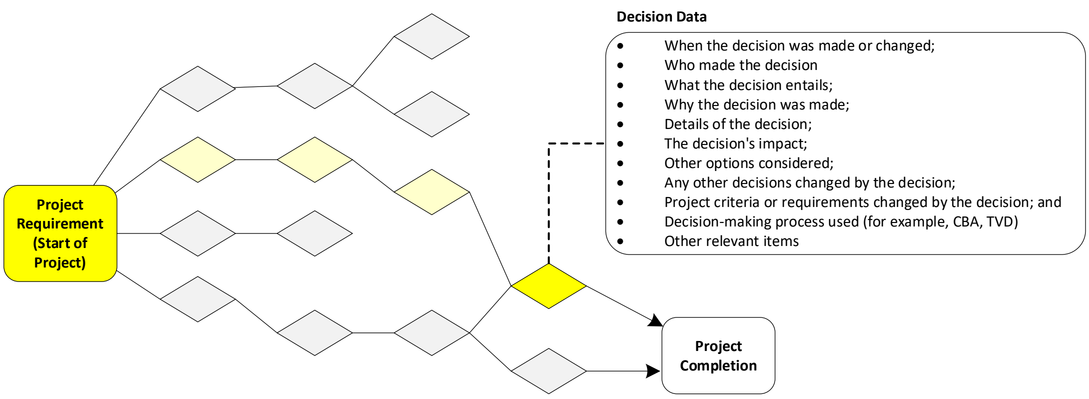


Figure 7.21: DDST decision tree diagram

7.9 Chapter Summary

This chapter acts as a point of reflection and an opportunity to conceptualise findings from previous chapters into a proposal for a DDSS – Decision Model and associated subsystem DDSTs. This DDSS and two of the proposed DDSTs (Data Classification system and DDST checklists) represent DSR artefacts as described in Chapters 3 and 4, while the remaining DDSTs described above represent opportunities for future research and development.

The validation interviews suggest the proposed DDSS and DDSTs present viable proof of concept methods for fulfilling Research Objective 4 and the broader goals of this research and the intent of the design science research methodology selected for this thesis. This is further discussed in Chapter 8 below.

8. FRAMEWORK VALIDATION AND RESEARCH DISCUSSION

8.1 Chapter Introduction

This chapter discusses and contextualises the proposed DDSS framework and associated DDSTs by discussing how they fit within typical AECO processes. The chapter then discusses a proof-of-concept web application that further develops the proposed Data Classification and Checklists (Sections 7.8.2 and 7.8.3). Efforts at validating the proposed DDSS framework and DDSTs are then discussed. The chapter concludes with a general discussion of the development of the DDSS as a DSR artefact.

8.2 DDSS Framework Overview within Typical AECO Processes

The following section conceptualises how the proposed DDSS framework can fit within a typical AECO design and construction project. To this end, Figure 8.1 (below) presents a graphic image of a conceptual reimagination of the building design and construction process that integrates a DDSS that facilitates the transfer of data, information, and knowledge from FM/O to AE-design. It does this through the development of what this thesis describe as a Decision Model. It further proposes the use of an *Analysis Model* that is noted but not developed in this thesis.

Within this conceptual framework, the term *phase* is intentionally avoided due to its connotation of sequential activities. The terms *activity* and/or *realm of influence* are preferred. It is true that the design and construction process inherently includes a series of semi-sequential activities. For example, you cannot design or construct a building before it is decided that one should be built. Nor can you construct a building before you know what you are constructing. However, design may influence the determination of what can or should be built. Similarly, construction may have a direct relationship with both the planning and design processes. Project activities are typically much more interconnected and influenced (or revised) by each other than typically indicated in project-phase representations of the process. Additionally, the bands represented in Figure 8.1 are purposefully not numbered to limit the view of them as strictly sequential activities. They are labelled using letters to aid in describing them rather than as an effort to represent an order of activity.

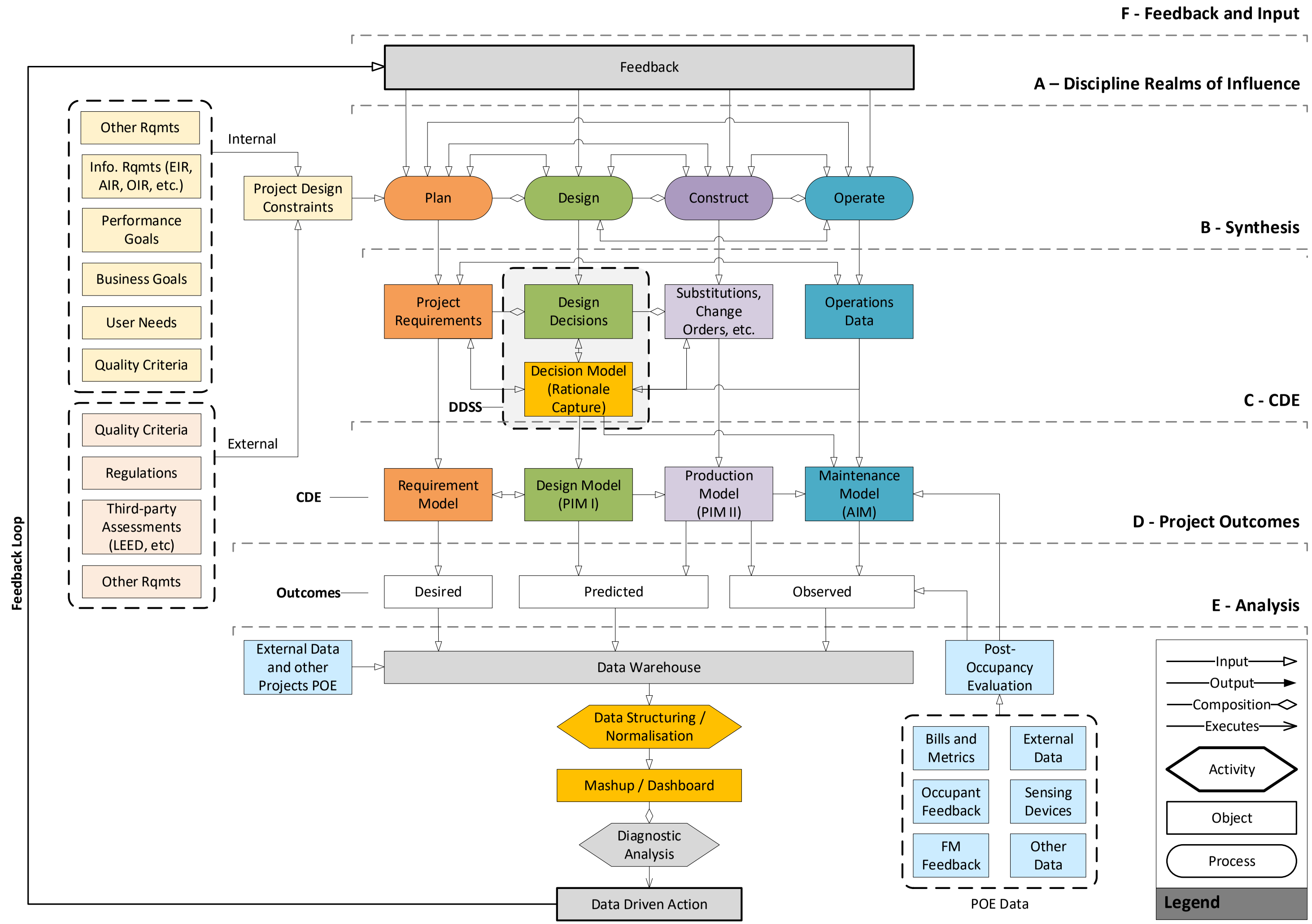


Figure 8.1: DDSS within AECO processes

A – Discipline Realms of Influence: Band A represents the traditional realms of the building design and construction process. Each realm is shown linked to the other realms due to their interconnected relationships. Both internal and external design constraints impact project criteria during the planning process (Section 7.3.1). In Band A, *Planning* provides a *composition* of project requirements, *Design* provides a *composition* of design elements, and *Construction* provides a *composition* as a bid or built project. A completed project is provided as a *composition* to *Operations*.

B – Synthesis: In Band B, Planning is primarily responsible for synthesising internal and external design constraints to establish project requirements. Design synthesises project requirements through design decisions to develop a project proposal. Through the process of design, project requirements may be revised or revisited. Similarly, through the act of construction, project requirements may be revised or revisited. Project requirements thus drive *and* are driven by other realms in the process.

Design decisions are recorded in a decision model that links design proposals and their rationale to design criteria and project requirements. This decision model is linked to the proposed DDSS to aid in the decision-making process and to provide the rationale and support for each design decision, which is recorded in the model. In this manner, the DDSS and decision model are inseparable and work together as one.

C – Common Data Environment (CDE): The output of each realm is shared through a common data environment – understood as a central repository where construction information is stored. The information stored in the CDE include documentation, graphical models, and other non-graphical assets and represents a single source of project information (McPartland, 2016).

In this band, project data, information, and knowledge are visualised and made shareable. This may be through traditional means such as written reports and drawings, or through digital data-sharing environments used with BIM. In this context, the CDE is an embodiment of the concept of *Ba* (Section 2.6) and acts as a shared space which serves as a foundation for knowledge creation (ibuunk, 2017).

D – Project Outcomes: Planning represents *desired* project outcomes. Design and early construction represent *predicted* project outcomes. Final construction and operation represent *observed* outcomes. Through the respective project models (requirement model, design model, decision model, production model, and asset maintenance model), desired and predicted project outcomes are stored in a data warehouse for future analysis and use.

E – Analysis: Data stored within the warehouse is structured and normalised for comparison. A classification filter (Section 7.8.2) may be applied to organise data according to AEC or FM/O knowledge structures. By normalising and structuring the data according to discipline appropriate ontologies, it may be visualised and compared within a data mashup and/or dashboard. In this context, a data mashup is understood as an application that uses data or content from more than one source to create a new service displayed within a single interface (Fichter, 2009). Data is also made available for AECO diagnostic tools. Data mashups and diagnostics are then able to drive data-driven actions and provide project feedback. Data analysis adds to AECO bodies of knowledge.

F – Feedback and Input: Diagnostic and analysis from current and past projects provide real-time feedback to each of the AECO project realms. The feedback loop applies to the full lifecycle of the project, individual phases, or individual decisions.

8.3 DDSS Framework Process Overview

An additional diagram representing how the proposed DDSS framework fits within the conceptual reimagination of the AE-design process described above but applied to the AECO design and construction process is indicated in Table 8.1 and Figure 8.2. In the following description of this process and associated diagram, numbers are used for identification purposes only, rather than a representation of specific, sequential events.

Table 8.1: DDSS framework process overview

DDSS Framework Process Overview within AE-Design Process				
1.	**At the beginning of a project, project feasibility and goals are determined based on business plan.**			
	a.	Prescriptive analytics is used to help determine the best way forward to meet project and business goals.		
	b.	Based on analytics, it is determined if defined project goals fit within business goals.		
		i.	If **NO**, project goals are revised based on business goals. Alternatively, business goals may be revised based on insights provided through prescriptive analytics, or the project may be deemed unrealistic and ended.	
		ii.	If **YES**, Project feasibility and project goals are used to determine project requirements.	
	c.	Key decisions are tracked in the decision model to facilitate future analytics and evaluation.		
2.	**Project requirements are determined and written to a project requirements model.**			
	a.	Predictive analytics are used to determine if defined project requirements will support business and project goals.		
		i.	If **NO**, it is determined if project requirements should be maintained or refined.	
			1.	If existing project requirements are maintained, business and project goals must be revised to fit with project requirements.
			2.	If project goals are to be refined, the process loops back, and new project requirements are developed, and the requirement model is updated with new project requirements.
		ii.	If **YES,** the process moves to design.	
	b.	Key decisions are tracked in the decision model to facilitate future analytics and evaluation.		
3.	**A design proposal is developed.**			
	a.	Predictive analytics are used to determine if the defined proposal will fulfil project requirements.		
		i.	If **NO**, it is decided if project requirements should be maintained or refined. If project requirements are not refined, a new design proposal is developed.	
		ii.	If **YES**, project requirements are refined to work with the initial design proposal, project requirements model is updated, and the design model written to the common data environment.	
	b.	Key design decisions are tracked in the decision model to facilitate future analytics and evaluation.		
4.	**After the design is completed, or simultaneously, the project enters construction.**			
	a.	Analytics are used to determine if the proposed design and construction methods will meet project requirements.		
		i.	If **NO**, it is decided if project requirements should be maintained or refined. If project requirements are not refined, a new design proposal or construction proposal is developed.	
		ii.	If **YES,** project requirements are refined to work with the initial design and construction proposal, project requirements model is updated, and production model written to the common data environment.	
	b.	As changes or revisions are made during construction, decision and requirements models are updated to facilitate future analytics and evaluation.		
5.	**After construction, the project enters the occupancy and use stage, and the asset information model is continually updated.**			
	a.	As the project is used and changes over time, descriptive and diagnostic analytics are used in conjunction with the requirements and decision models to determine if the project functions as intended and if it continues to meet business goals.		
		i.	If **NO**, it is determined if the project no longer meets business goals.	
			1.	Project goals and requirements can be revised and updated to reflect the new reality. The requirements and decision models are updated, and the project continues to be used.
			2.	The project may be terminated, and a new facility or alternative pursued.
		ii.	If **YES,** the project decision and requirements models are continually updated, and occupancy and use continue.	
	b.	As changes or revisions are made during occupancy, decision and requirements models are updated to facilitate future analytics and evaluation.		

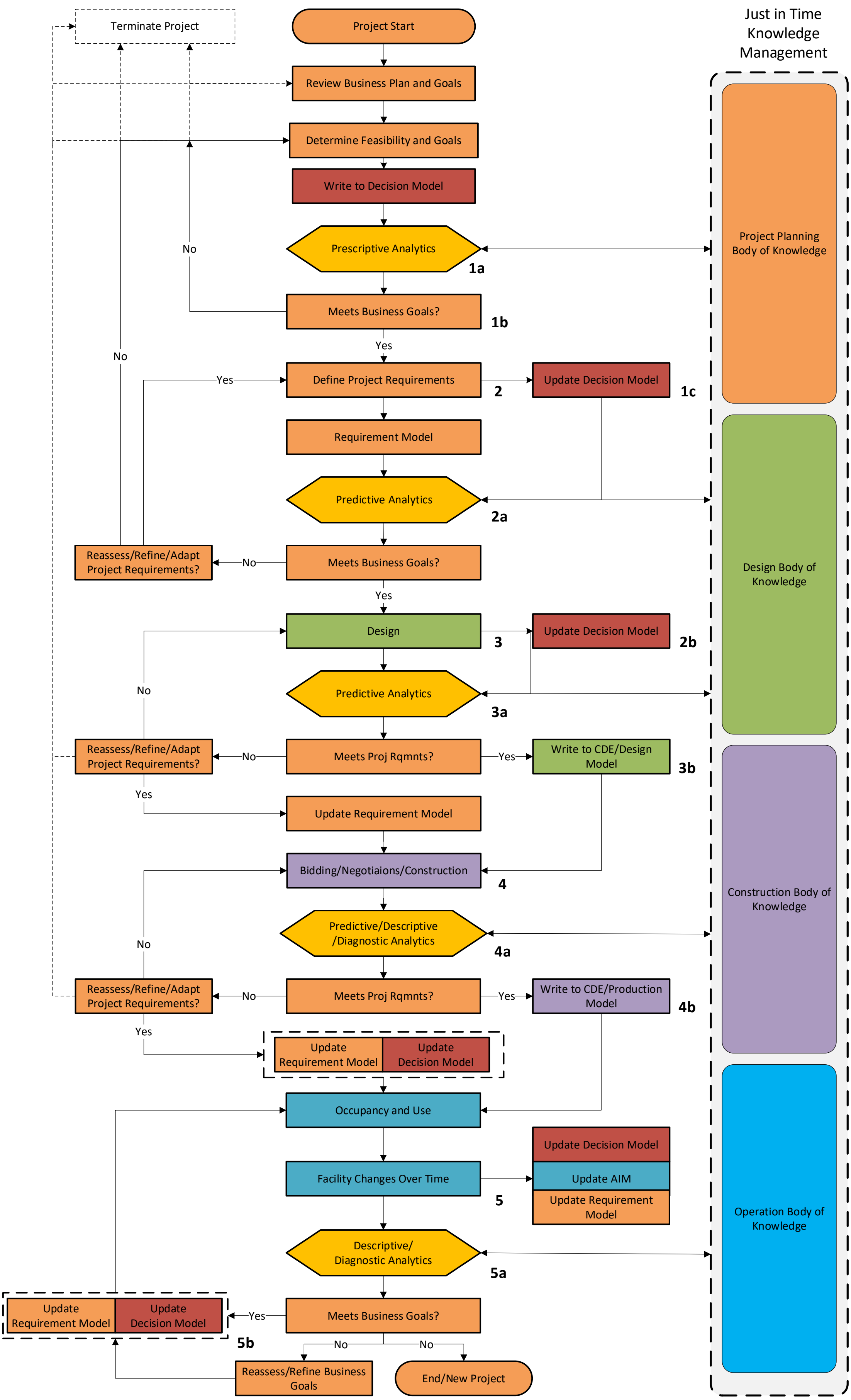


Figure 8.2: Decision model viewed within a project's phases

8.4 Proof of Concept Web Application

The proposed DDSS and DDSTs discussed in Chapter 7 were presented conceptually. They represented foundational research intended to be developed further through future research. However, due to the fundamental nature of the proposed classification system DDST discussed in Sections 7.6.1, 7.6.2, and 7.8.2, and the associated DDST checklists discussed in Sections 7.6.2 and 7.8.3, these proposed DDSTs have been developed further than the others. The author suggests these two DDSTs provide the foundation for the remaining DDSTs, such as the data store, or decision capture, and the broader DDSS itself. Therefore, it is justified that they are developed more fully, and further development of the remaining proposals be left for future work (Section 9.4).

The DDST checklists presented in Section 7.8.3 were presented as fully functioning artefacts and are validated as discussed in Section 8.4.1. As presented above, these checklists are intended to be used as paper forms or digitally filled out in a spreadsheet or similar application. They can also be linked to a local database. However, in such use, they fall short in seeking improved design decisions through increased knowledge sharing between AE and FM/O. Paper forms, or digital data limited to individual teams, do little to solve existing knowledge sharing problems. Furthermore, with such use it would be labour intensive for the information collected to feed the proposed DDST Datastore and broader DDSS. To this end, a proof-of-concept cloud-based application is developed incorporating the data classification system and proposed DDST Checklists. By creating a cloud-based application, information collected through the checklists can be added to a prototype database and provides the foundation for future development of the proposed DDST Datastore (7.8.4). This also provides a foundation for future development of the proposed BPM Decision Capture (Section 7.8.5) and proposed Data and Decision Tree Diagrams (Section 7.8.6).

The application Zoho Creator (creator.zoho.com) is used to develop the digital proof-of-concept DDST Checklists. Creator uses a combination of relational and key-value databases underneath; however, a range of data store and database types could be used to support the proposed DDSS. Due to the difficulty in presenting a digital application in printed form, a narrative overview of the application is provided in Figure 8.3 and in the text below. Screen captures, and associated descriptions are also provided to further describe the application.

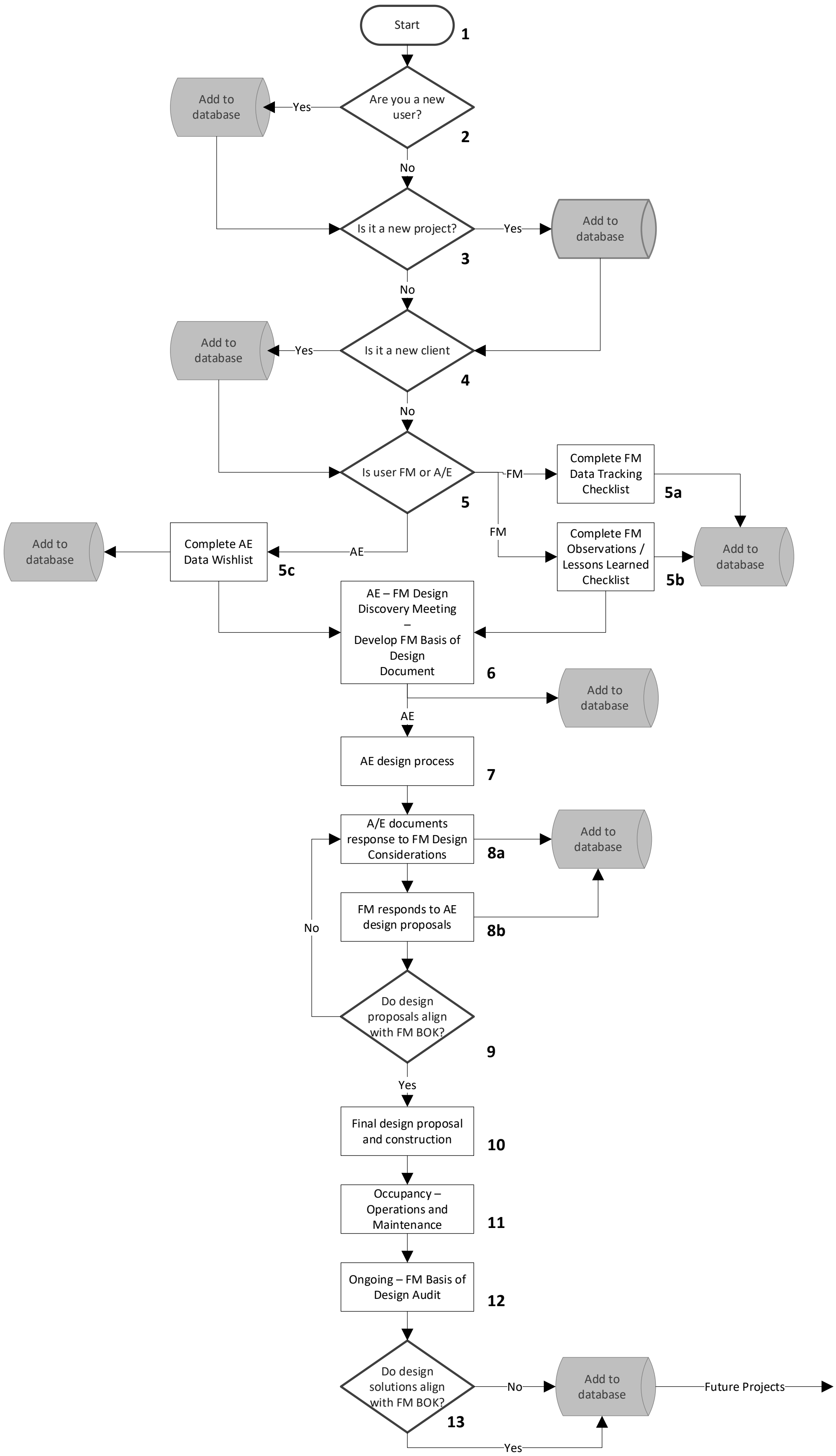


Figure 8.3: DDSS web application flow chart

8.4.1 DDST Checklist Proof of Concept Narrative Overview

Figure 8.3 is keyed to the following numbered steps to describe the use of the proposed DDST Checklist web application in a narrative form.

Step 1. At the beginning of a new project, project stakeholders are provided access to the application and associated database.

Step 2. If the user has not accessed the application previously, they are asked to provide background information. This includes information such as their job title, company they work for, or projects worked on. This information is stored in the database for future reuse and for linking projects, decisions, information, or data. If the user is an existing user with their information already stored in the database, this step is skipped (Figure 8.4).

Step 3. If the user is starting a new project, project information is recorded in the database. This includes information such as the project type, client, location, phase, occupancy type, and narrative description. This information is stored in the database for future reuse and for linking to projects, decisions, information, et cetera. If the user is accessing an existing project previously stored in the database, this step is skipped (Figure 8.5).

Step 4. If the project being accessed is associated with a new client or owner, not previously recorded in the database, their information is recorded. This includes information such as client type and other client projects stored in the database. If the client has been previously inputted into the database, this step is skipped (Figure 8.6).

Step 5. In Step 5, users are asked to perform a series of tasks dependent on their project role. These steps directly correlate to the DDST checklists presented in Sections 7.6.2 and 7.8.3. Where they were previously presented as paper checklists or digital forms completed in a local spreadsheet or word processor file, here they are filled out via the web application that directly feeds an underlying database. This allows for future reuse, cross referencing, or queries.

a. If the user is associated with FM/O, they are asked to document what FM/O related data they track. This data is classified by the user according to the Data Classification DDST categories presented in Sections 7.6.1 and 7.8.2. In addition, users are asked to identify how the data is tracked (file types, et cetera) and provided perceived value or importance of the data (from the user's viewpoint). This information is stored in the underlying database for future reuse, cross referencing, and queries (Figure 8.7).

b. If the user is associated with FM/O, they are asked to briefly describe any important considerations or lessons learned from FM/O which may pertain to the design of the associated project. They may also identify any items they think should be addressed in the associated project design. Users are asked to categorise these items based on the provided knowledge categories. Users are also asked to provide a perceived importance for each item. Finally, users are asked to identify if they have file types that pertain to each inputted item. This information is stored in the underlying database for future reuse, cross referencing, and queries (Figure 8.8).

c. If the user is a member of the AE team, they are asked to identify from which FM knowledge areas they would like to receive facility related data and information. They are also asked to identify their preferred format to receive the data and an anticipated value of the data (from the user's viewpoint). This information is stored in the underlying database for future reuse, cross referencing, and queries (Figure 8.9).

Step 6. In Step 6, both FM/O and AE related users are asked to come together to discuss the information collected in the previous steps. This represents the first necessary, in-person coming together in the proposed process and is used as an opportunity to discuss and explain the data collected in the previous steps and to develop an *FM Basis of Design*. This step is a direct response to data collected in the semi-structured interviews and questionnaire, as well as the validation phase. Respondents consistently expressed their belief that face-to-face interactions were necessary to explain the data, and that the digital transfer of data or information was insufficient.

Step 6 specifically represents the FM Basis of Design checklist discussed in Section 7.8.3. In this step (Figure 8.10), AE and FMs work together to identify FM related project concerns and goals. In this manner they are similar to the Dialogue Meetings proposed by Støre-Valen (2021) in Section 2.4. These FM basis of design items are categorised, and cross referenced, based on the proposed DDST knowledge classification categories. For each item, a value is assigned based on the project importance of that item (0 – 4, where 0 has no value and 4 is essential). Information collected in the form is then saved to the database for use throughout the project and subsequent projects. This FM/O basis of design can then be used to track individual design decisions and their effectiveness over the life cycle of a project. Throughout the project the criteria from the FM/O basis of design is reviewed, evaluated, and scored in Step 8 below.

Step 7. Step 7 represents the ongoing design process and is not directly associated with the proposed DDSS web application.

Step 8. In Steps 8a, 8b, and 8c, AE and FM/O users are asked to revisit the FM Basis of Design established in Step 6. Throughout the project the criteria from the FM/O basis of design is reviewed, evaluated, and scored. At each of these reviews, the AE-design team documents how they addressed each item from the checklist. The FM/O team then evaluates the design proposal, and the AE-design team's responses and assign a value 1 – 4 for how well they feel the proposed response address the item (0 is not addressed and 4 completely addresses the listed concern). This process is repeated over the life of the design process as well as the life of the facility (Figure 8.11, Figure 8.12, Figure 8.13).

Because the FM Basis of Design and associated responses are scored by both the AE and FM/O stakeholders, the effectiveness of design proposals, or design decisions, can be graphed and viewed visually. Over the life of a project, AE's view of design proposals can be compared to the FM/O’s views identifying where they diverge or match.

Step 9. Step 9 represents the final design proposal and associated construction process and is not directly associated with the proposed DDSS web application.

Step 10. Step 10 represents the ongoing occupancy, operations, and maintenance phases of a project and is not directly associated with the proposed DDSS web application.

Step 11. Steps 11a and 11b represent the ongoing review and evaluation of the FM Basis of Design established in Step 6 and revisited in Steps 8. During operations and maintenance, the FM Body of Knowledge (BOK) is regularly reviewed. Documented design decisions and supporting rationale are reviewed and rescored over the course of the project’s life. This information is then stored to the database for reuse by the AE or FM/O teams on future projects. In doing so, it provides a method for AE teams to evaluate the effectiveness of their design proposals, and it also adds to the general body of knowledge. Because design proposals and evaluations are categorised by the proposed data classification system and are stored in the database, this information can be queried on future projects. It therefore becomes a searchable database of lessons learned and the effectiveness of design proposals and solutions (Figure 8.14).

Screen captures associated with each of the steps above from the proof-of-concept web application are provide in the following section.

8.5 DDSS Web Application Screen Captures

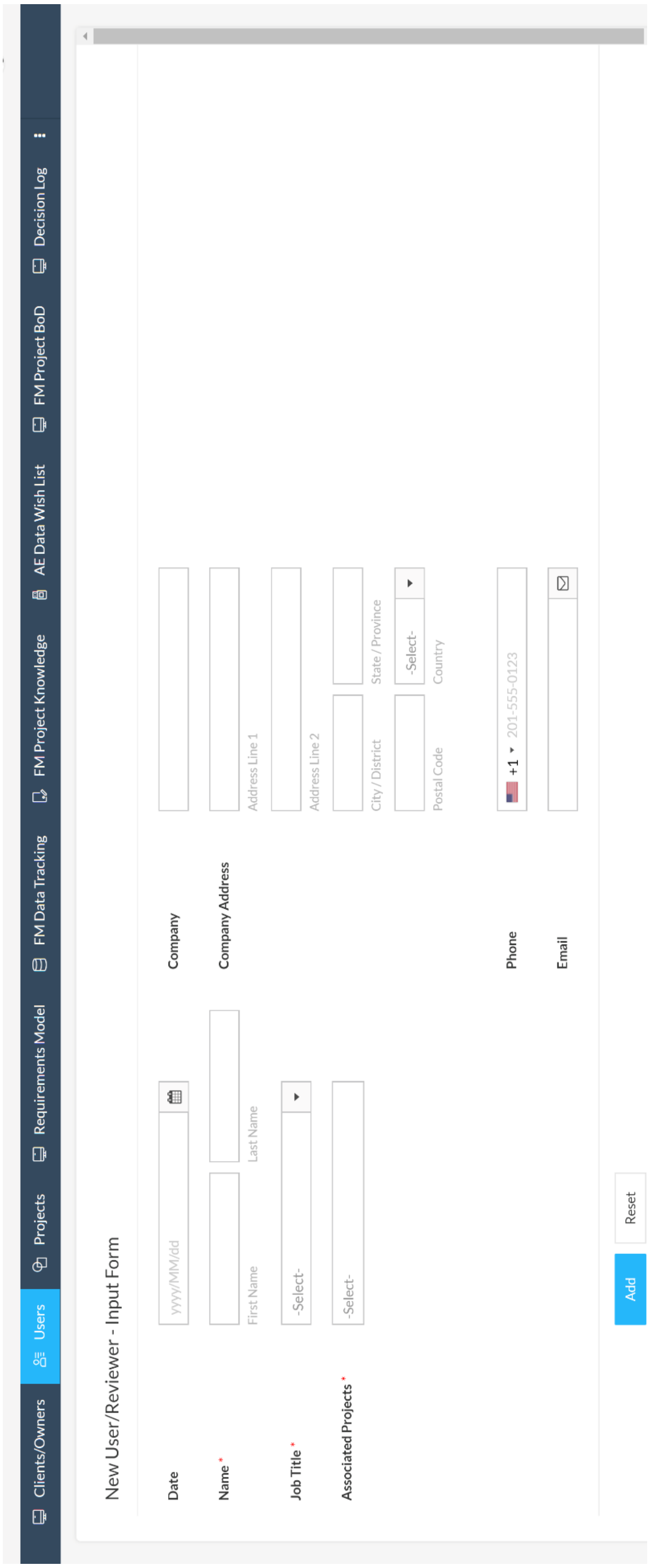


Figure 8.4: Proof of concept web application – new user input

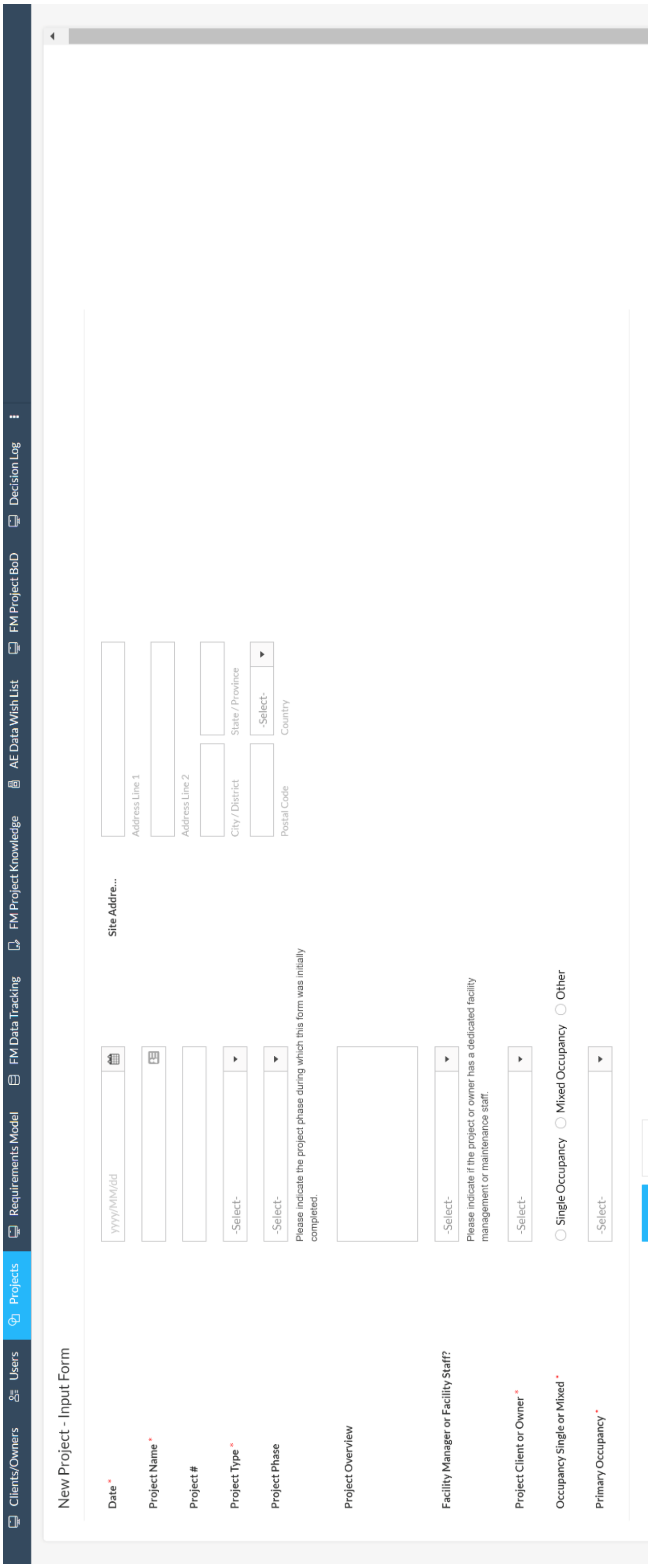


Figure 8.5: Proof of concept web application – new project input form

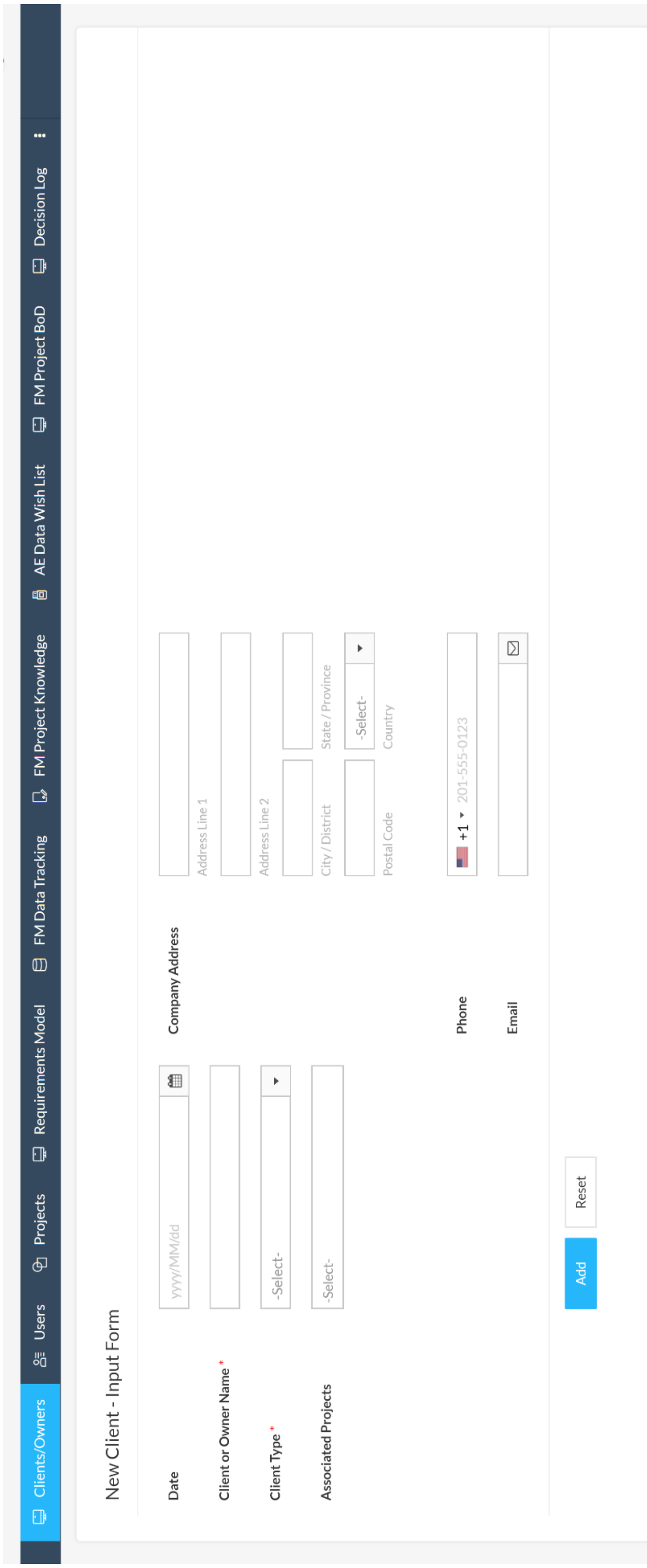


Figure 8.6: Proof of concept web application – new client input form

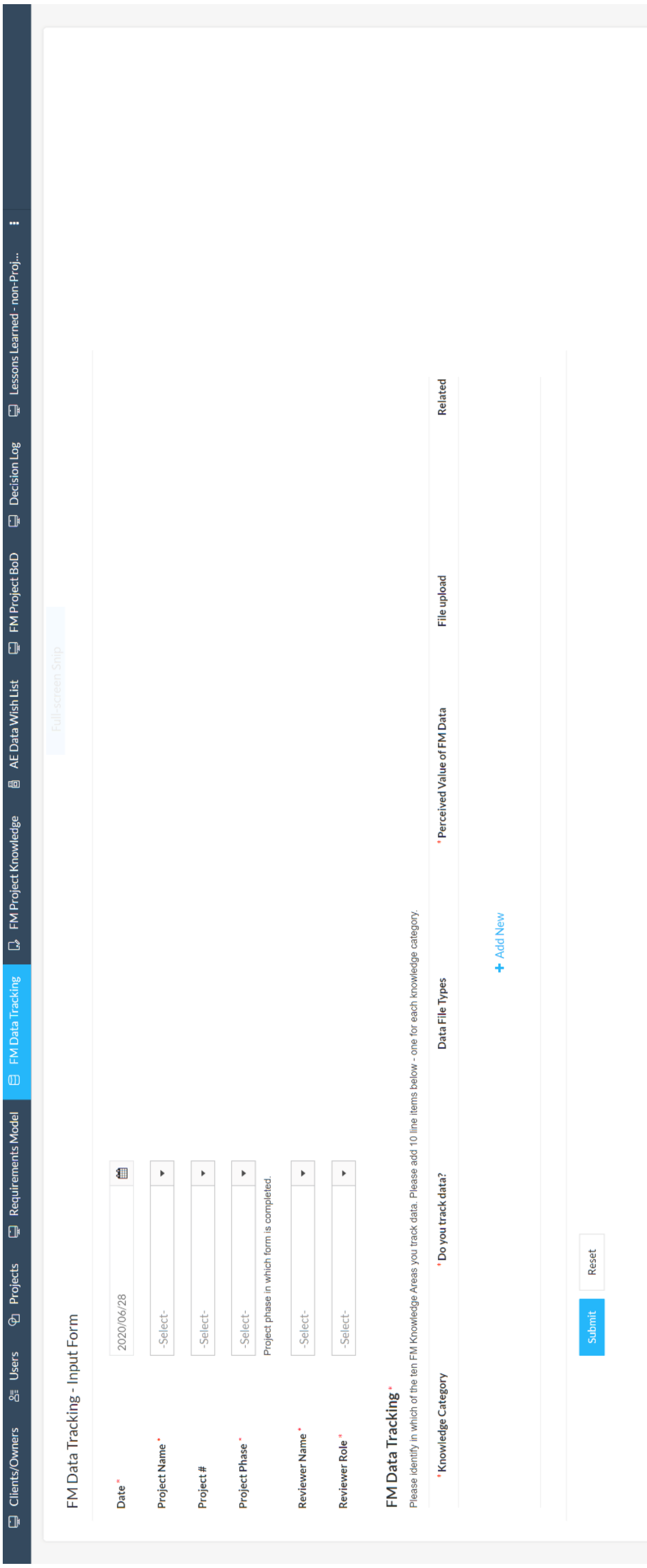


Figure 8.7: Proof of concept web application – FM data tracking input form

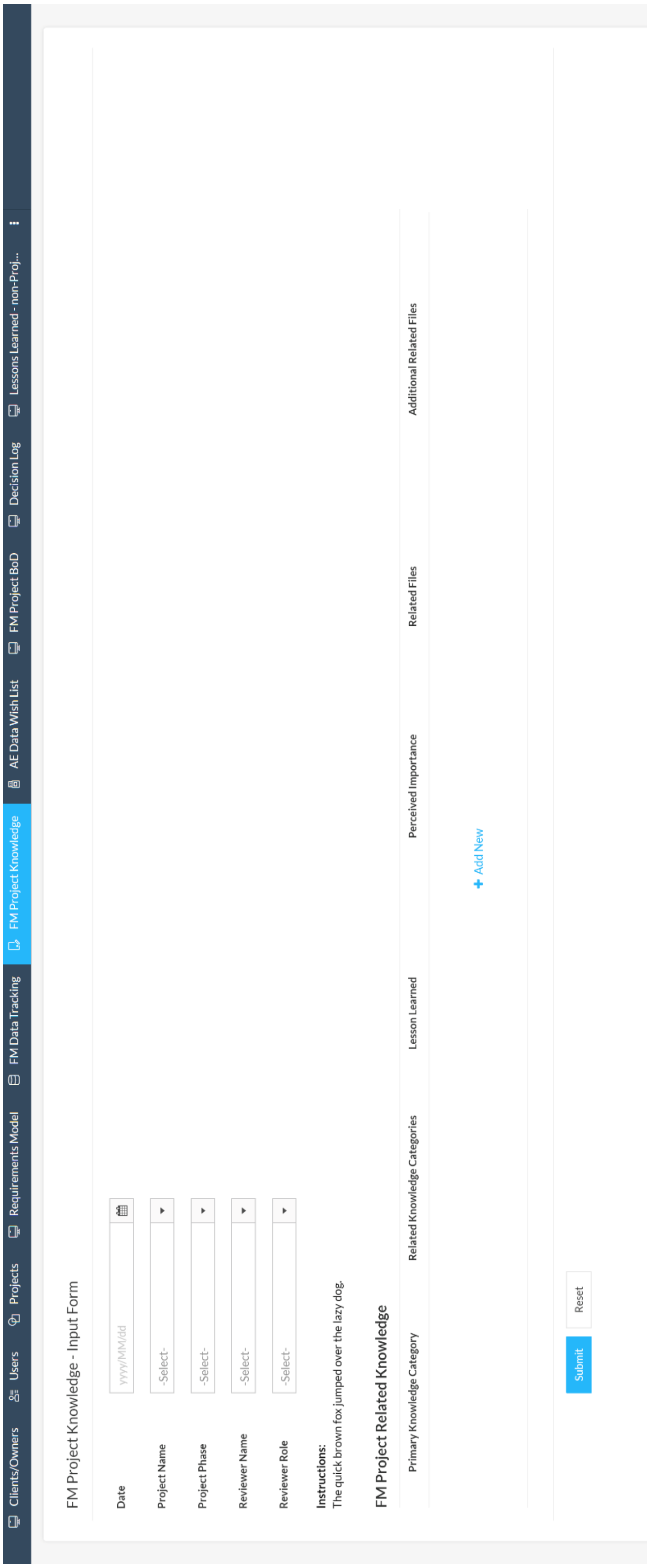


Figure 8.8: Proof of concept web application – FM project knowledge input form

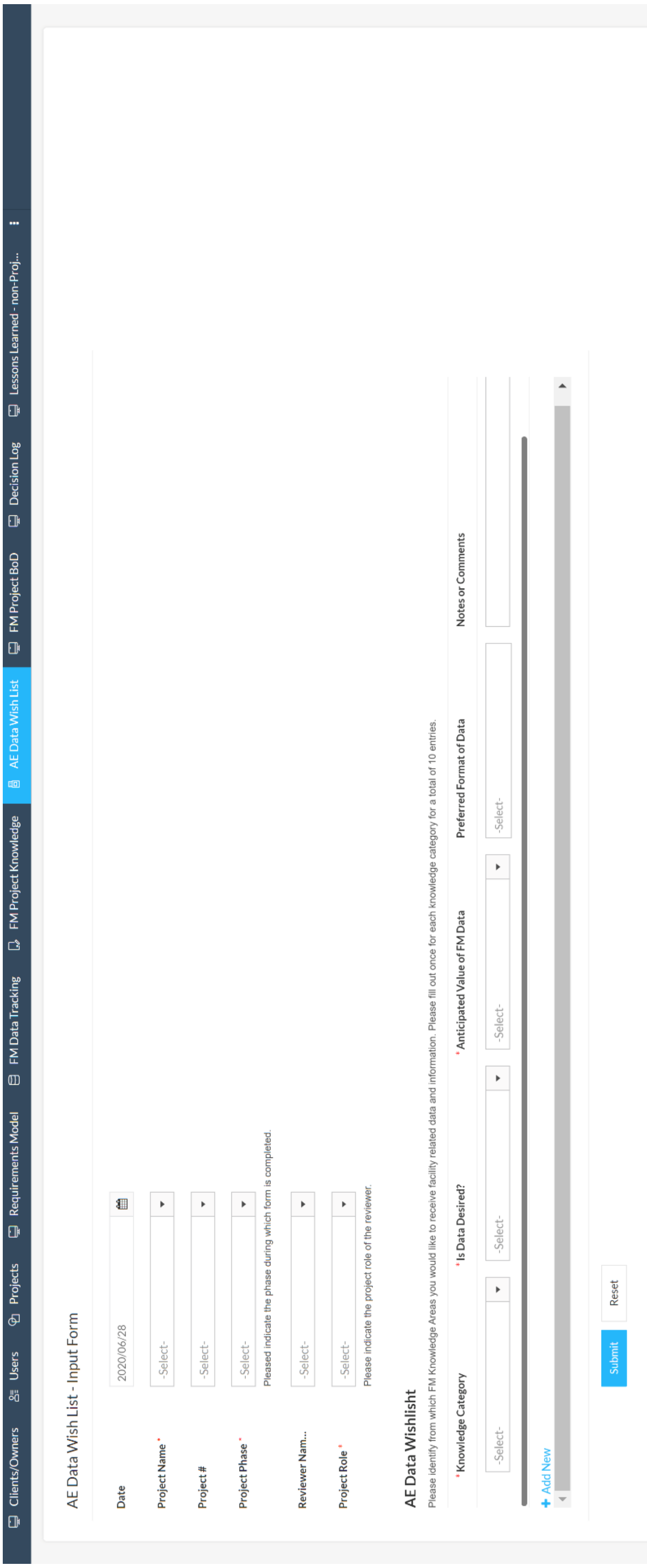


Figure 8.9: Proof of concept web application – AE data wish list input form

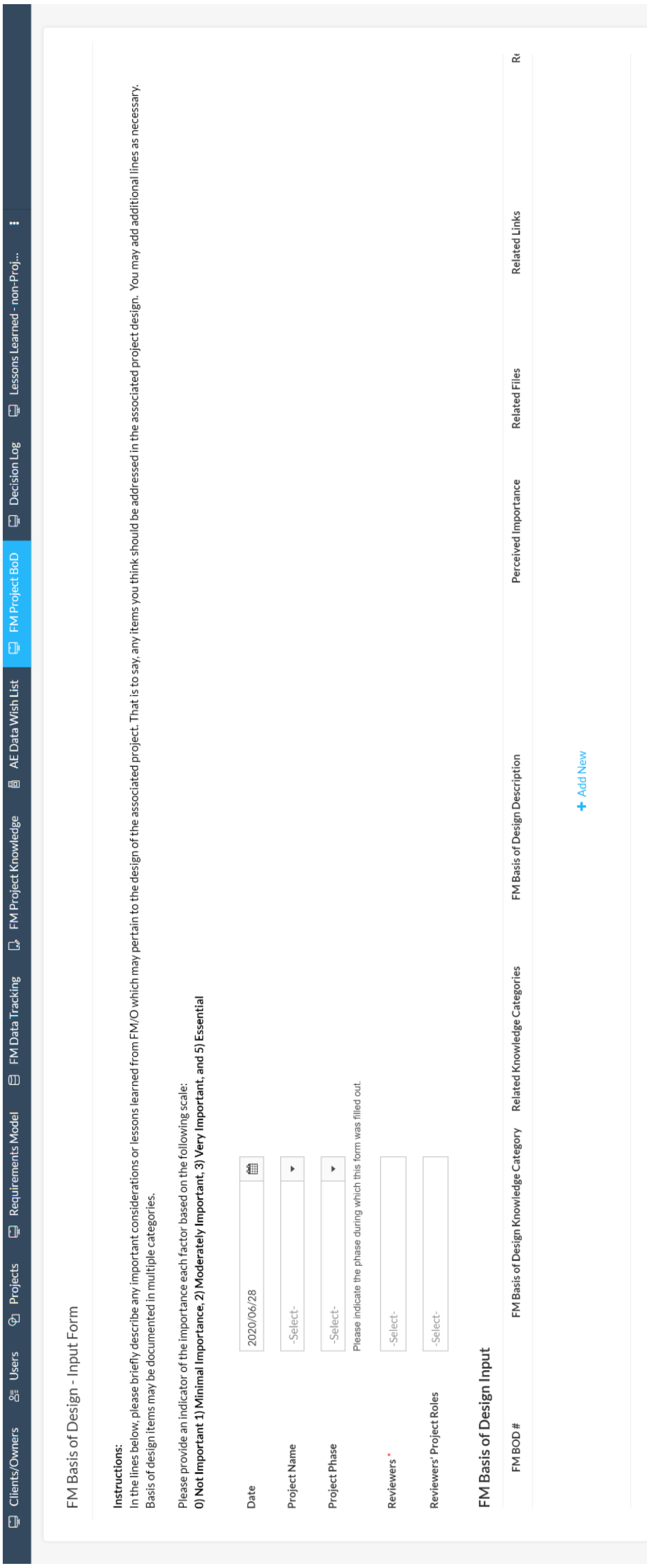


Figure 8.10: Proof of concept web application – FM basis of design input form

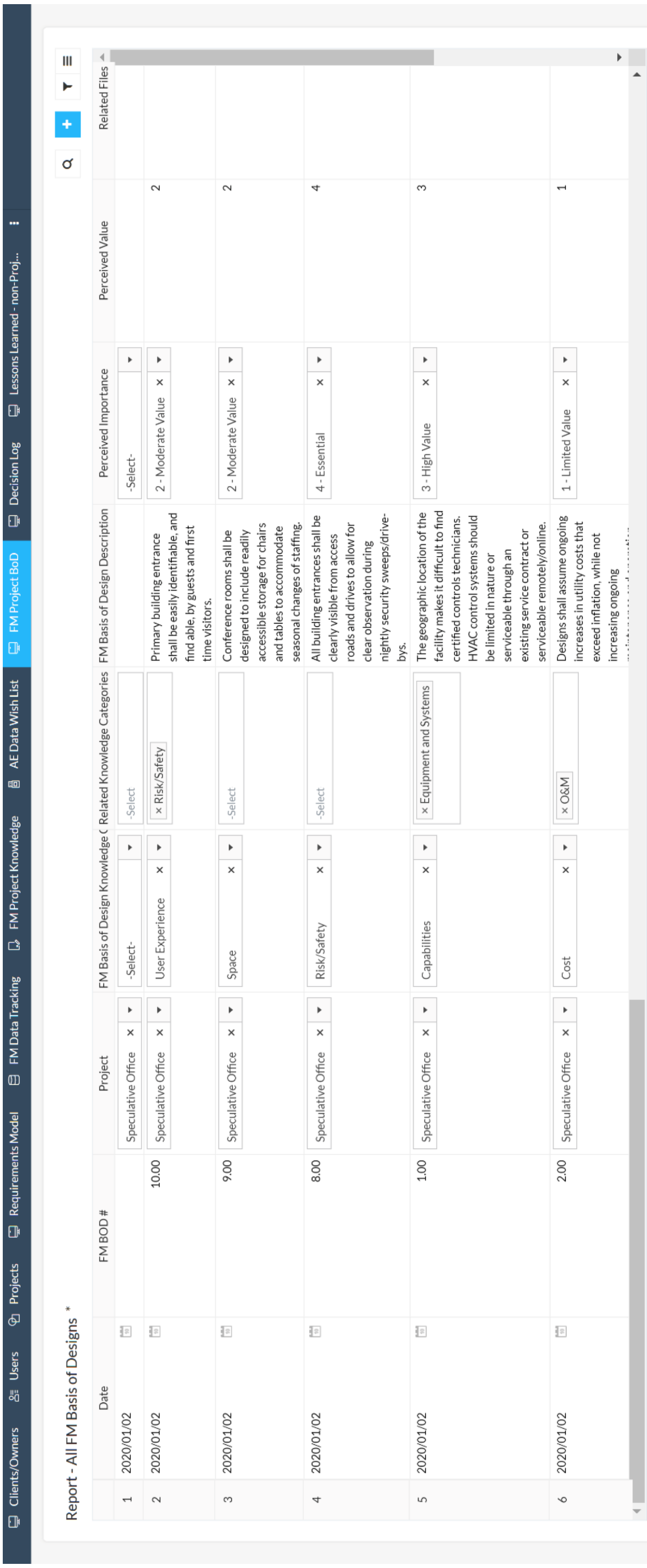
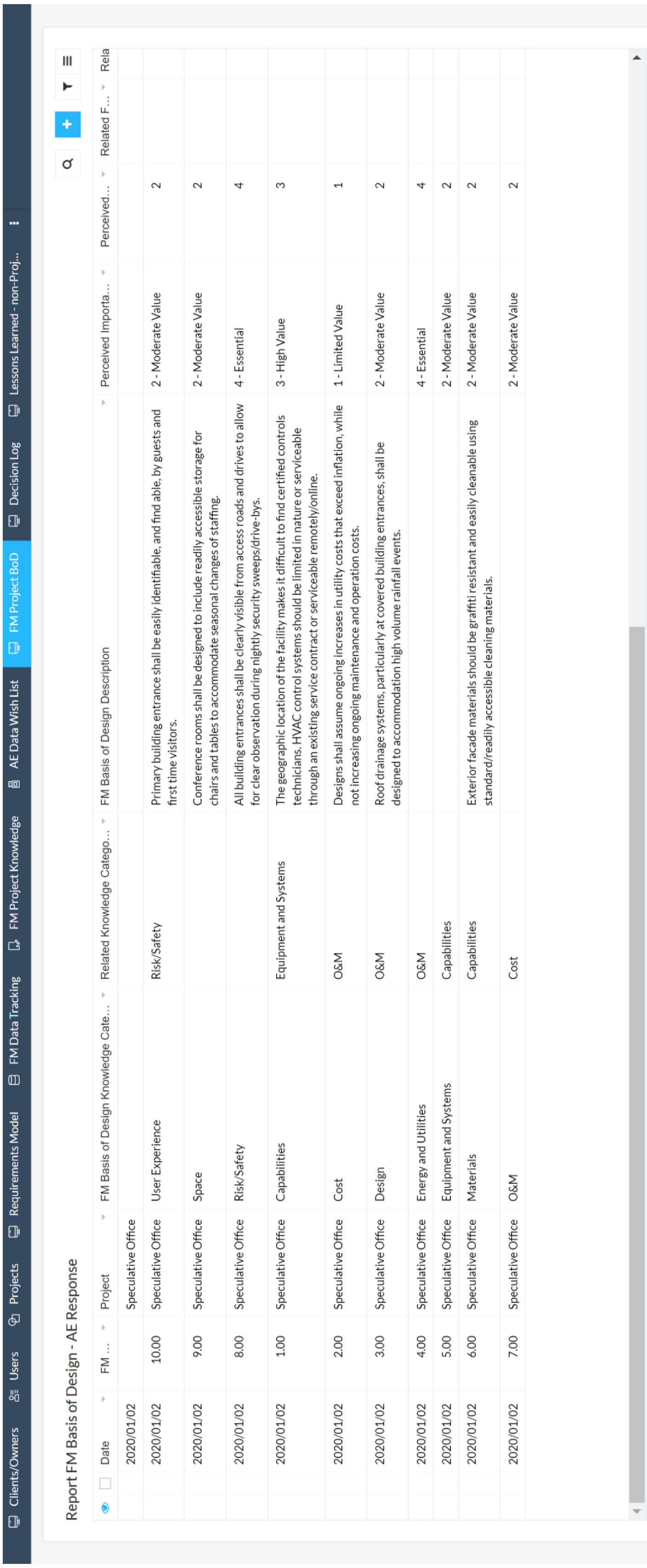


Figure 8.11: Proof of concept web application – FM basis of design report



Date	FM ...	Project	FM Basis of Design Knowledge Cate...	Related Knowledge Catego...	FM Basis of Design Description	Perceived Importa...	Perceived...	Related F...	Rela
2020/01/02		Speculative Office							
2020/01/02	10.00	Speculative Office	User Experience	Risk/Safety	Primary building entrance shall be easily identifiable, and find able, by guests and first time visitors.	2 - Moderate Value	2		
2020/01/02	9.00	Speculative Office	Space		Conference rooms shall be designed to include readily accessible storage for chairs and tables to accommodate seasonal changes of staffing.	2 - Moderate Value	2		
2020/01/02	8.00	Speculative Office	Risk/Safety		All building entrances shall be clearly visible from access roads and drives to allow for clear observation during nightly security sweeps/drive-bys.	4 - Essential	4		
2020/01/02	1.00	Speculative Office	Capabilities	Equipment and Systems	The geographic location of the facility makes it difficult to find certified controls technicians. HVAC control systems should be limited in nature or serviceable through an existing service contract or serviceable remotely/online.	3 - High Value	3		
2020/01/02	2.00	Speculative Office	Cost	O&M	Designs shall assume ongoing increases in utility costs that exceed inflation, while not increasing ongoing maintenance and operation costs.	1 - Limited Value	1		
2020/01/02	3.00	Speculative Office	Design	O&M	Roof drainage systems, particularly at covered building entrances, shall be designed to accommodation high volume rainfall events.	2 - Moderate Value	2		
2020/01/02	4.00	Speculative Office	Energy and Utilities	O&M		4 - Essential	4		
2020/01/02	5.00	Speculative Office	Equipment and Systems	Capabilities		2 - Moderate Value	2		
2020/01/02	6.00	Speculative Office	Materials	Capabilities	Exterior facade materials should be graffiti resistant and easily cleanable using standard/readily accessible cleaning materials.	2 - Moderate Value	2		
2020/01/02	7.00	Speculative Office	O&M	Cost		2 - Moderate Value	2		

Figure 8.12: Proof of concept application – FM basis of design AE response report

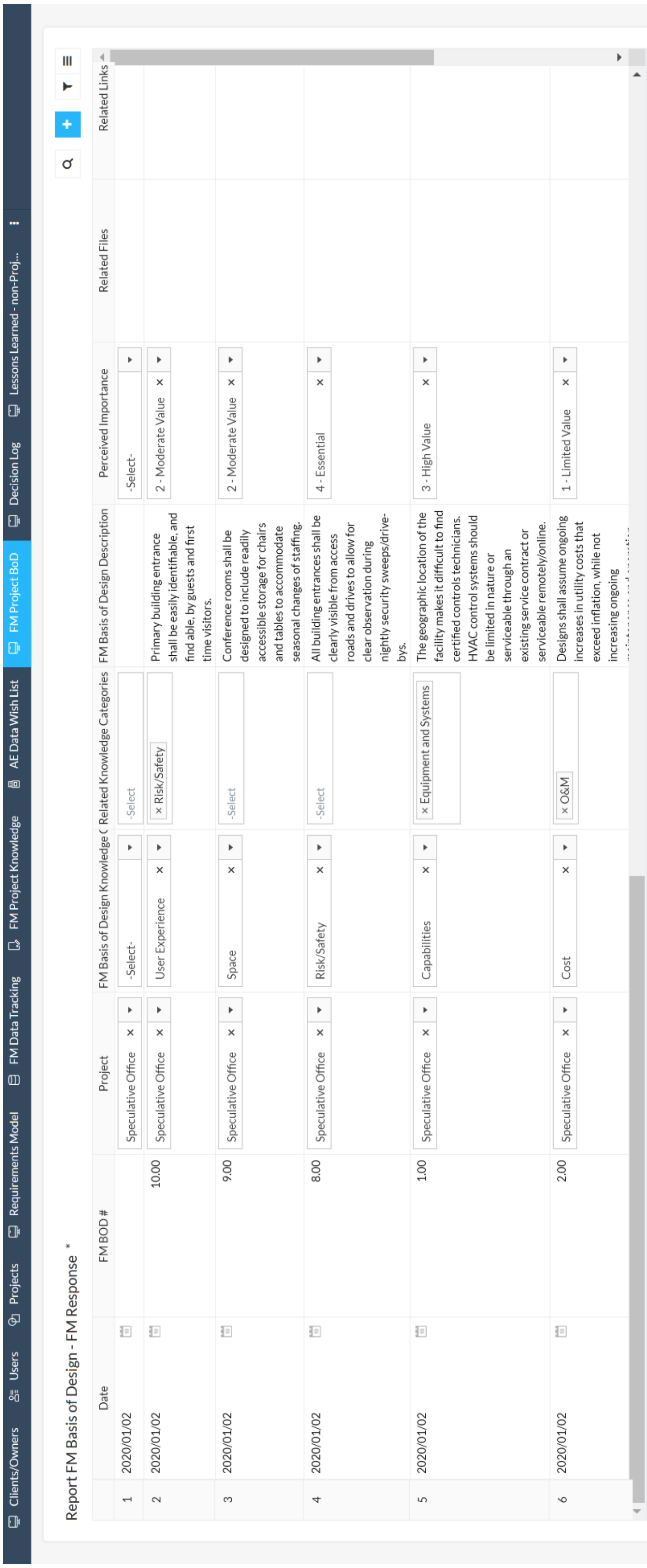


Figure 8.13: Proof of concept application – FM basis of design FM response report

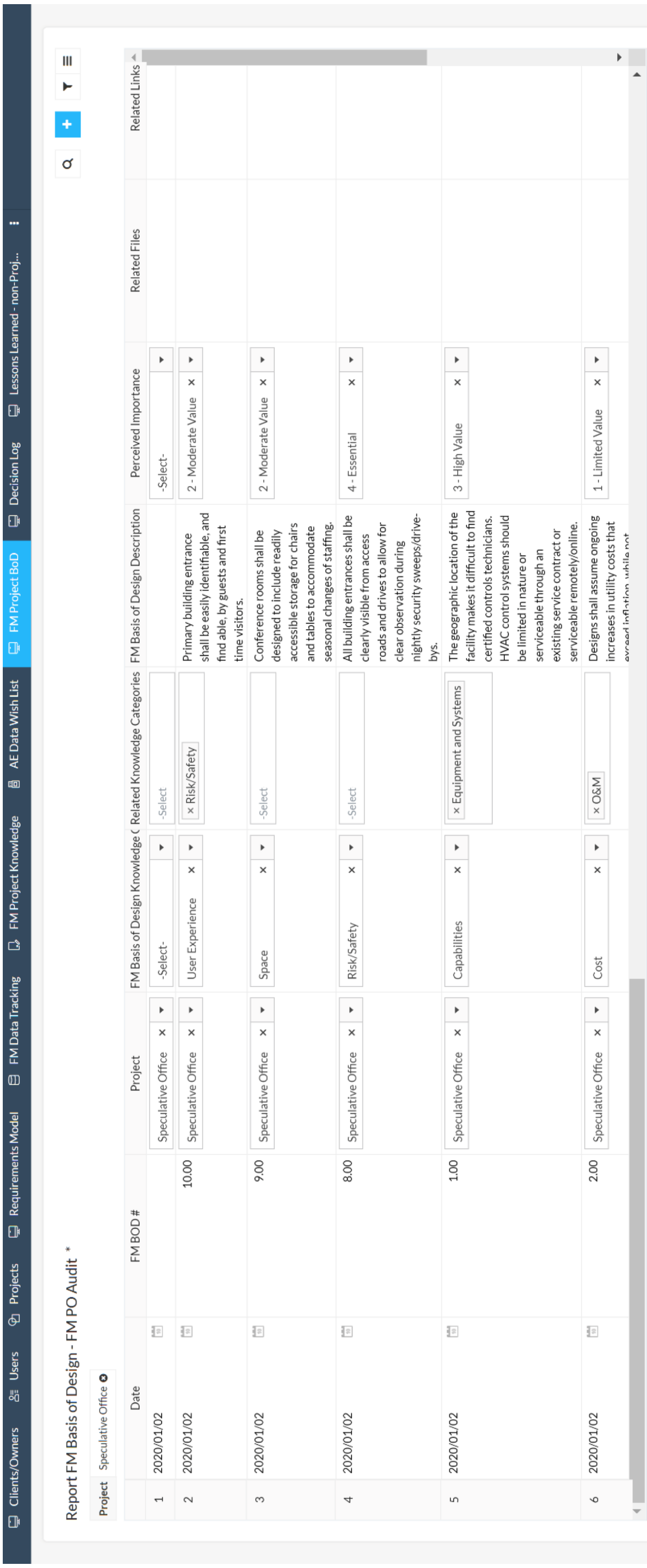


Figure 8.14: Proof of concept web application – FM post occupancy audit report

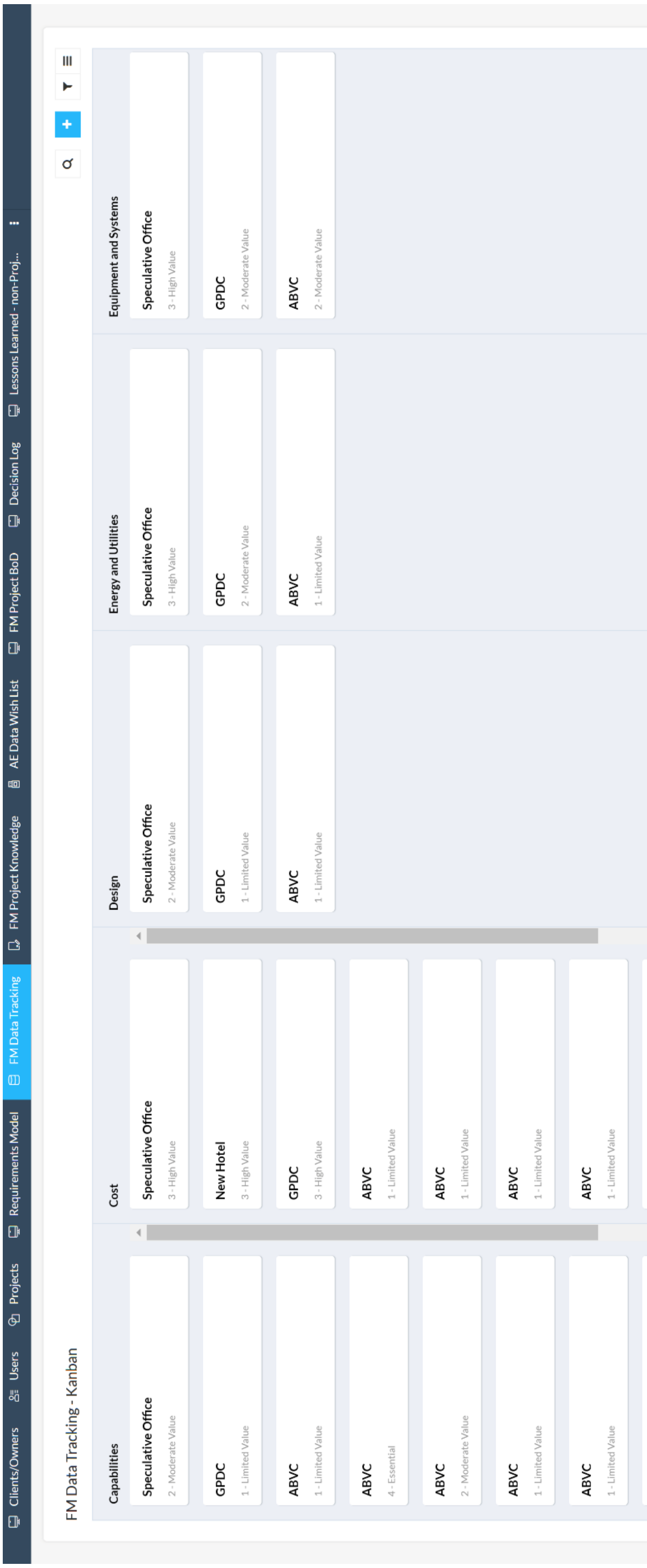


Figure 8.15: Proof of concept web application – sample FM data tracking report

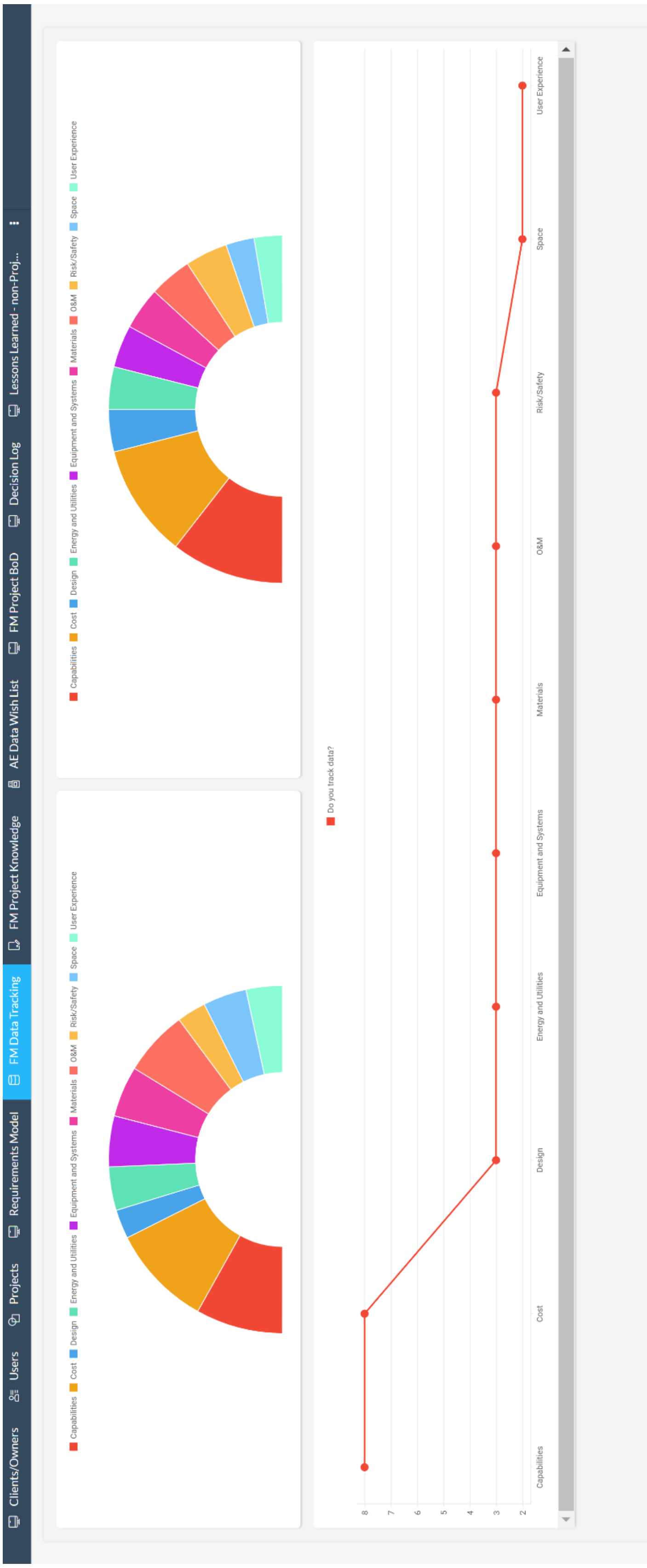


Figure 8.16: Proof of concept web application – sample graphical report

8.6 DDSS and DDST Validation

To this point, the proposed DDSS framework and associated DDSTs have relied on a variety of information resources to present the research: the literature review, semi-structured interviews, and online questionnaires. In addition to the online questionnaire used to validate and refined the proposed data classification DDST (discussed in Section 7.8.2), the proposed DDSS framework discussed above and subsystem components (DDSTs) were validated through a series of validation interviews with 10 practicing AE designers and FM professionals (see Table 4.7).

These experts had relevant professional experience in AE-design, FM, or in some cases experience in both. All the experts used in the validation phase worked at the time in either the AE or FM/O profession in the United States, thus providing the views of practicing professionals within the targeted community of practice. In keeping with the discussion presented on research reliability in Section 4.7, representative quotes are provided below to 1) support the identified themes; 2) help demonstrate the consistency of themes and quotes; and 3) ensure transparency of the research process (Saini & Shlonsky, 2012).

8.6.1 Validation Interviews – Discussion

The interviewees were first asked if they thought the research aim was legitimate, that is, if they thought the problem(s) the proposed artefacts seek to address can be seen in their professional experience. The working professionals unanimously held that there are real and persistent issues with FM information and requests being shared with AE-design teams and reflected in built projects. They also unanimously and often enthusiastically agreed with the fundamental premise of the research.

> **VI-2 FM (49:48):** I love where this is going.

Despite their enthusiasm for the research question, participants recognised there are many difficulties that would need to be overcome to improve FM/O – AE knowledge sharing. The interviewees agreed that a method for classifying knowledge was an important step in improving interdisciplinary knowledge sharing. However, participants made clear that they thought it was important that the classification system be adaptable to different projects and contexts. This was reflected by one of the interviewees who stated:

> **VI-2 FM (36:43):** … a huge variable is that the design of every building is going to be different… There are also other functions that go into it, they are looking at the cultural things. They are looking at the environment, they are looking at different things… How would you account for that? Because then those are going to be huge variables are not going to be consistent from project to project.

Participants suggested the data classification system would help address this issue. They liked that the system allowed for the classification of knowledge in addition to the classification of objects. They further felt the ability to classify information in multiple categories was beneficial as was the open-endedness of the proposed system. However, they felt this open-endedness may also be problematic as the categories were quite broad and the system may need some method for developing sub-categories.

> **VI-7 AE (52:32):** The open-ended nature of the classification system is good, but you may need to provide some subcategories for the different knowledge categories, which would then help prompt them a little bit further, potentially. For example, like we were saying, sustainability is kind of a subsection of each one of those.

Interviewees consistently suggested one of the problems with knowledge sharing between AE and FM/O that would need to be overcome is that the professions generally are not aware of each other's information needs, or what each other are able to share. One participant succinctly described this issue by stating:

> **VI-3 FM (43:08)**: And that is the challenge, how do you address the challenge that a lot of times the facility managers, they don't know what they don't know.

However, participants proposed that the use of checklists or other measures that nudge AE and FM/O into sharing what information they track or what they want would be helpful in this regard. Participants expressed a belief that the proposed checklists would help address this use and that they would help nudge the participants towards increased interaction. Furthermore, they felt cloud-based checklists would function better than paper or email-based measures and that the ability to link to a database was important.

> **VI-3 FM (21:48):** I would sit down with them and be like... what are the normal things that you inventory that you typically assign PMs to, right? What is your inventory classification standard? Then you know which assets you need at earmark. Then I would also ask them, have them fill out a survey. What are the pieces of information you want for that? Do you want a PM checklist? Do you want the estimated cost, the price of the asset, you know, all these things, right? And then they start filling that out

> and basically what they, the answer that they should be giving you is populating the database.

Validation participants consistently held a similar view with those gathered in the semi-structured interviews, and online questionnaire: that early but ongoing FM/O involvement with AE-design teams is important. Participants felt that tools that promote early interaction between AE-design teams and FM/O was important, but it is also necessary to provide a mechanism that promotes ongoing interaction.

> **VI-3 FM (14:42):** …the integrated project design method. And so, you know, it goes to me, I think that is procedural. I would look at that, as like having, like the discovery meeting upfront with the FM sitting there. The FM does not necessarily have to vocalise like a ton of stuff. However, a lot of times what I would see them doing is, is an idea floating. And they would be like, well, wait a minute, wait a minute. We may not want to do it that way because of this or that.

Participants universally liked the idea of the FM basis of design meeting as being helpful in ensuring FM knowledge is incorporated into AE-design processes. They further supported the use of checklists prior to this meeting as a method to prime or nudge the meeting. However, they also felt ongoing interaction and feedback between teams would be necessary to ensure FM/O concerns and knowledge is integrated into final projects. To this end, validation participants felt the proposed processes – that score and evaluates the FM basis of design over the course of a project – would be beneficial. They also liked the proposed ability to visualise how FM concerns are scored in relation to AE proposals. They felt this would help ensure their concerns make it into built projects.

> **VI-6 AE (1:03:24):** They could see what other people listed as cost. They could see how it was proposed to be addressed and then they could say did that really work for that, meet the design intent or not… We could see like did they do what they indicated. We should be able to see alignment. Did they align? Because it is an ongoing score over time. You could have an SD score, a DD score, a CD score. I would see this form growing in length, right? You do this for SD, you do it for DD, you do it for CD, you would do it after a year and you would do it at five years. Presumably, you are either going to see alignment or you are going to see diversion, or you are going to see some other thing over time. But it is not a single moment. It is not a single piece of paper. So not only have we established the design intent and that informs future meetings, but we can track it.

Architecture and Engineering team members within the validation group expressed their belief that the proposed assessment and scoring method would particularly be beneficial when utilised over the life of the project during occupancy. The designers in the group expressed frustration that too often they have no idea how their design proposals work out or function during occupancy and that they appreciated the ability of the proposed DDST to track design decision outcomes both during design but also during occupancy.

> **VI-2 FM (13:28):** … if you had some sort of database but would have to be incorporated is also the end user, each, decisions. So not just contract drawings and contract submittals, but as-builts [as well]. You could see what happened and track it.

Not surprisingly AE participants were more receptive to the proposed DDST BPM decision capture. They liked the idea of being able to attach decision history to BPM product models and BPM objects. They universally felt this ability would improve design processes and allow better decision tracking and validation. However, they also universally felt the process would need to seamlessly fit into standard design processes, and if the measure were not easy to incorporate into their processes, it would likely not be used. They suggested the BPM represents a worthwhile area of future research to pursue. One architect in the group shared an example of a recent project he had worked on where such a tool would have been particularly useful.

> **VI-10 AE (15:40):** Having a decision tracking tool tied to the BIM model would have been extremely helpful in this situation because it would have helped us understand when the ceiling was placed in the model and why. It would have saved me hours of work trying to track down the reason for the change in the model.

Given the relatively minimal use of AIMs identified among all participants in this research (interviews, questionnaires, validation interviews), it is not surprising to the researcher that FM/O validation participants would not support the proposed BPM decision capture DDST to the extent AE participants did. However, FM/O validation participants did see benefit to the proposed Decision Tracking diagram DDSTs. They felt the ability to visually track a decision-making process while linking it to building outcomes would be helpful. This view is reflected in one participant's suggestion that:

> **VI-2 FM (54:20):** …there is something that needs to come off that is an indicator that this, this has got a problem. You know, even as simple as a green, yellow, red light. But something that shows that this area is still either a decision has been made decisions and limbo decision has been, our response hasn't been made or this is as a conflict, whatever it is that that's got to be able to have triggers built into the system. So almost kind of like a [decision] enunciator.

8.6.2 Validation Interviews – Identification of Future Work

Throughout the interviews used for validation of the proposed DDSS and DDSTs, several concerns were raised by participants that suggest areas for future research. While Section 9.4 discusses areas of potential future work associated with the broader thesis, areas of future work specifically identified through the validation effort are identified and briefly discussed here. (A broader discussion of future work can be found in Section 9.4.) Issues raised by validation participants to be explored as part of further work include the following categories (briefly discussed below):

1. Subcategories of classification system
2. Database and security
3. Document control

Subcategories of classification system: Participants were supportive of the proposed data classification system but felt that it would need to be adaptable to a variety of projects and project types. To this end they suggested it may be necessary to provide or allow for subcategories within the classification system. However, they felt this research would be best to incorporate into pilot project studies using the proposed system during test projects.

Database and security: Participants had two primary concerns regarding the proposed DDSS and associated database. The first concern was that the database function within existing workflows and not require significant work on the part of the users to maintain. Second, while they were receptive to the idea of data, information, and knowledge sharing between projects and users, the issue of security was a concern. Participants universally felt that security and anonymity would need to be addressed for the proposed system to fulfil its potential to improve design decisions.

Document control: Document control within the proposed DDSS and DDSTs was a repeated concern raised by validation participants. Given the number of people involved in the process, participants felt it would be necessary to establish clear document control to maintain the database and associated documents.

> **VI-2 FM (52:33):** But I know what I think is document control because that is going to be a portion of this. If you're going to utilise, even if it's in a digital format, you're going

to have to have some sort of document control process that built into this, or this is going to go away. It is going to go the way of the dodo.

8.6.3 DDSS and DDST Validation and Reflection

The validation effort discussed above took place both during and after the development of the proposed DDSS framework and associate DDSTs. This allowed the DDSS and DDSTs to undergo changes and be revised throughout the development process based on feedback from the participants. This effort was undertaken to be in keeping with the Define, Measure, Analyse, Improve, and Control (DMAIC) process described by Webber and Wallace (2011). The DMAIC process is illustrated below in Figure 8.17.

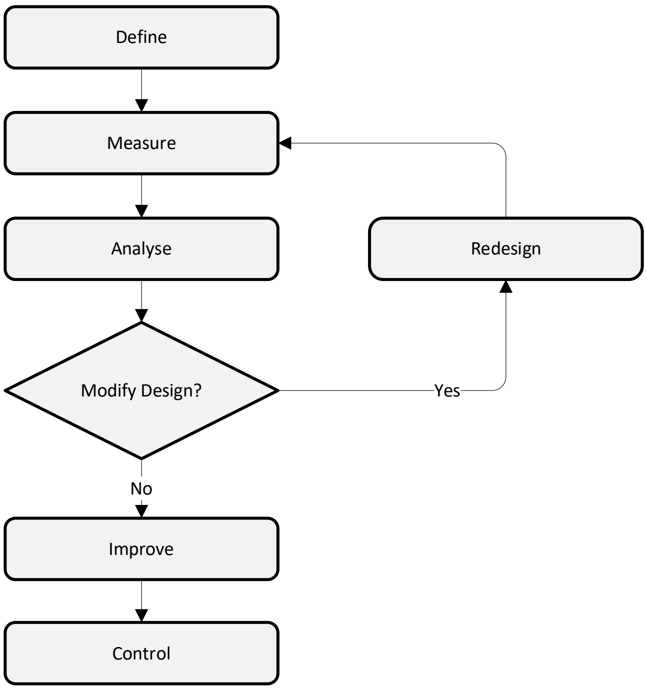


Figure 8.17: DMAIC process diagram

The validation efforts presented in the section above led to several changes in the proposed DDSS and DDSTs: however, three revisions standout out as significant in the author's view:

1. The proposed knowledge classification categories (Section 7.8.2) were revised in direct response to a validation online questionnaire (see Section 7.8.2.1 and Appendix H and I) and validation interviews.
2. The proposed DDST checklist that establishes a scoreable and trackable FM basis of design was developed through feedback from validation interview participants.

This was not seen as a necessary component of the DDSS and DDSTs prior to validation interview participant feedback.

3. The scoring mechanism, which assigns perceived value to data and design decisions, came out of validation participant feedback. Participants encouraged the development of a scoreable system that is trackable over the course of a project. They further thought the potential of the proposed system was worthwhile and something they perceived as a valuable addition to the AECO process.

Based on the feedback from the validation effort, as well as the direct improvements made to the proposed DDSS and DDST, the author views this effort as successful.

8.7 DDSS and DDST Design Science Artefact Discussion

This research utilised a DSR strategy. The starting point of DSR is the view that something is not quite right in the world and needs to be changed. To this end, DSR seeks to develop artefacts that are introduced to the world to make it different or better. Design science research is specifically defined by Johannesson and Perjons (2014, p. 7) as the "scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest." This research began with the view that the AE-design process could benefit from better sharing of FM/O information and knowledge with AE-design teams. It further sought to develop a DSR artefact that improves the sharing of FM/O knowledge into AE-design teams.

The proposed DDSS and DDSTs described in this thesis, are presented by the author as DSR artefacts. The author contends these artefacts meet the goals and requirements of DSR, and that the remaining research objective is fulfilled (Objective 4 - Section 7.2):

> **Research Objective 4**: To develop and validate a conceptual framework that supports AE-design decisions by facilitating data, information, and knowledge sharing between facility management and operations (FM/O) and AE-design teams.

In Table 8.2, key requirements and aspects of DSR (see Section 3.2.4) are presented alongside a discussion of how the proposed DDSS and DDSTs fulfil these requirements.

Table 8.2: DDSS and DDSTs fulfilment of design science research requirements

DDSS and DDSTs Fulfilment of Design Science Research Requirements	
Design science research requirements	**This research**
New Knowledge: van Aken (2005) describes the goal of design science research as the development of new knowledge, which professionals in the field(s) associated with the research can use and implement in their practices.	Through the development of the proposed DDSS and DDSTs this research develops new knowledge which can be implemented in AE and FM/O practices.
Design science as an artefact: It produces descriptive, explanatory, and predictive knowledge. This process of knowledge generation manifests itself in the design, building, and application of an artefact (Hevner et al., 2004; Markus et al., 2002). Design science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation (Hevner et al., 2004, p. 82). Markus et al. (2002) find the production of an artefact as a part of the design science process helps researchers better understand the problem before them.	The proposed DDSS and DDSTs represent DSR artefacts that incorporate the knowledge gained and data collected through the research process. The proposed DDST classification system and associated checklists represent functioning artefacts.
Rigorous methods: Design science as a research methodology must make use of rigorous research methods (Johannesson & Perjons, 2014). Design science research relies upon the application of rigorous methods in the construction and evaluation of the design artefact (Hevner et al., 2004, p. 82).	The development of the proposed DSR artefacts relied on rigorous research methodologies such as a literature review, semi-structured interviews, online questionnaires, and validation interviews.
Design science as a search process: The search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment (Hevner et al., 2004, p. 82).	The proposed DSR artefacts were developed through existing means of research to reach the desired ends. Furthermore, existing practices with the associated fields of practice were recognised and accommodated.
Existing Field: The knowledge it produces must be related to an existing field of research and associated knowledge base to ensure research outcomes are well founded and original (Johannesson & Perjons, 2014).	The research in this thesis is founded on existing knowledge and practices in AE and FM/O fields. The literature review was conducted from within the existing knowledge base of the professional fields and participants were drawn from practicing professionals.
Communication of Research: Research outcomes and results must be communicated to a broader audience of practitioners and other researchers (Johannesson & Perjons, 2014). Design science research must be presented effectively both to technology-oriented as well as management-oriented audiences (Hevner et al., 2004, p. 82).	Research outcomes were presented to practicing professionals through validation interviews.
Problem relevance: The objective of design science research is to develop technology-based solutions to important and relevant business problems (Hevner et al., 2004, p. 82).	The relevance of the research problem associated with this research was validated through multiple measures: literature review, interviews, online questionnaire, and validation interviews.
Design evaluation: The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods (Hevner et al., 2004, p. 82).	The proposed DDSS and DDSTs were presented to and validated by practicing professionals within the fields of research.
Research contributions: Effective design science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and design methodologies (Hevner et al., 2004, p. 82).	Responses to the proposed DDSS and DDSTs from working professionals during the validation phase suggest the proposed design science artefacts reflect contributions to the professional realms of practice associated with the research.
Utility: Hevner et al. (2004, p. 92) identify *utility* as the fundamental question of design science research. They ask: "What utility does the new artefact provide?" and "What demonstrates that utility?" Design science research and associated evidence must address these two questions. Without utility, there is no contribution from the research; and if existing methods are adequate, then new artefacts are unnecessary.	The validity of the research aim associated with this thesis was repeatedly verified through the literature review, interviews, and questionnaires. This suggests existing methods are inadequate and new artefacts are necessary. The feedback from the validation interview participants when presented the proposed DDSS and DDSTs suggests the research provides utility. That, if incorporated into existing processes, it would provide improvement over existing practices.

8.8 Author's Reflection and Research Discussion

This research is based on a view of design that fundamentally sees design as a form of problem solving. This is not to suggest that design does not have an artistic or aesthetic component or quality, but rather that design, at its heart, is grounded in solving problems effectively (Dorst & Lawson, 2013; Papanek, 1985; Rowe, 1994; Simon, 1996). Design without its problem-solving component is more akin to artistic expression. With this view of design, this research seeks to enhance AE-design decision-making processes by improving the quality of the information available to designers. To this end, this thesis approached the research aim and objectives from the view of design. The research could have similarly been approached strictly from an FM/O point of view, a programming point of view, or a construction management point of view.

If design is viewed as a problem-solving exercise, issues concerning access to, and availability of, information and knowledge quickly become evident. Due to the additive nature of design, that one phase builds on previous phases, early design decisions have a more profound impact on an overall design than decisions that come later in the process. However, it is during these early design decisions that designers have the least amount of information related to a project (Ipsen et al., 2021; Roberts et al., 2020). This thesis therefore tries to enhance the design decision-making process by enhancing the information and knowledge available to building designers earlier in the design process by accessing the knowledge and experience of facility managers.

Inherent in this view of design, and fundamental to this thesis, is the view that designers have bounded rationality (Simon, 1996). A designer cannot know everything about the design and construction of a building; therefore, they must rely on knowledge and information from others to fulfil their responsibilities as designers. Additionally, as buildings get increasingly complex and the expectations for the finished projects are more demanding, the need for designers to rely on outside knowledge is more pronounced. Most people, designers included, are constrained in how they work and to what they can achieve. There are simply limits on how much information an individual can integrate or process (Sloman & Fernbach, 2018). This leads the author to the view that not only is design fundamentally a problem-solving exercise, but it is also a communal activity. No designer can master every facet of a building design.

Even the simplest building design now requires a complex web of knowledge and understanding of the design, construction, and operation of a building.

This research then seeks to expand and improve the communal reach and resources of AE-design teams. The inclusion of FM knowledge into the AE-design process enhances AE's community of knowledge (Sloman & Fernbach, 2018). It does this by including the knowledge of experience from those who live with the results of AE-design decisions on a day-to-day basis. While this research has sought to enlarge the AE-design community through better integration of FM/O, it could likewise be expanded through other realms, for example, environmental psychology, construction management, or finance.

Design is the product of a community, not an individual. It is through our ability to collaborate and jointly pursue complex undertakings that we can produce seemingly complex outcomes such as the construction of a modern skyscraper. In this way, design is understood as a community of knowledge, and not the sole realm of individual geniuses. Therefore, by improving and expanding the community of knowledge, we can improve design outcomes. According to Sloman and Fernbach (2018), within a community of knowledge, having access to knowledge is more important than having the knowledge yourself. Sloman and Fernbach Sloman and Fernbach (2018)further suggest much of human understanding is based on an awareness of what knowledge is already out there. Sophisticated understanding generally consists of knowing *where* to find the relevant information. However, for that knowledge to be useable across a community of knowledge, the community of knowledge must be structured properly or consist of several key elements: First, members of a knowledge community must be able to share information intentionally; Second, the different components each member of a knowledge community have to contribute must be compatible; and Third, our knowledge must be structured in a way so that the information we expect to gain, or be filled by others, has an appropriate place to go.

This thesis, and the proposed DDSS and associated DDSTs directly seek to improve and expand the AE knowledge community through the inclusion of FM/O. The proposed DDST classification seeks to structure knowledge and information from each realm in a manner that is compatible and shareable. Furthermore, it seeks to provide a place for outside information "to go" – in the words of Sloman and Fernbach. And finally, the proposed checklists and web application seek to provide a mechanism for knowledge community members to share information intentionally. The researcher hopes the work presented here will help others see the problem solving and communal aspect of the AE-design process, and that the proposed DSR artefacts will act as functional tools which help expand built environment knowledge sharing communities.

9. CONCLUSION

9.1 Chapter Introduction

This thesis presented a literature review and mixed method, DSR strategy to examine the research aim and objectives. The research formed the basis for the development of a conceptual framework that supports AE-design decisions by facilitating information and knowledge sharing between FM/O and AE-design teams.

This chapter concludes this thesis by revisiting the research aim and objectives. Discussions are presented below as a commentary on each research objective, summarising how each objective was fulfilled. This chapter summarises and presents key outcomes and discusses contributions to knowledge from an academic and professional viewpoint. The chapter also discusses research limitations and makes recommendations for future work.

9.2 Reflection on the Research Aim and Objectives

This thesis began with an initial literature review that found that facility managers have unique insights that strategically position them to play an important role in facility design because of their active engagement with the built environment. However, despite the potential benefit from the increased involvement of FM in AE-design, research has found that sharing knowledge and information between design and FM teams is limited. This practical problem led to the development of the research aim: *To develop solutions that facilitate information and knowledge sharing between FM/O and AE-design teams*.

To pursue this aim, four research objectives were developed. These objectives were addressed through a literature review, mixed methods data collection, and a DSR strategy that led to the development of a conceptual framework (DSR artefact).

In completing the thesis, the author finds the four research objectives and aim were fulfilled. While the findings for each objective were discussed throughout the thesis, they are also summarised below. The following sub-sections present conclusions for each objective and highlight key findings.

9.2.1 Observed Problem

As a result of their active engagement with the built environment, facility managers have unique insights that strategically position them to play an important role in facility design; however, knowledge sharing between design and FM teams is limited.

The observed problem, which represented a point of departure, was primarily informed by a scoping literature review. Findings from the literature review were also reinforced and validated through data collected from working AECO professionals.

The literature review found AE and FM/O are typically viewed as distinct disciplines; however, despite this separation, the importance of integrating operational knowledge, information, and data with design is recognised as a means for improving building design decisions. Furthermore, prior research suggests it is possible to improve design decisions, and subsequent building operations, by integrating the advice of non-design specialists as early in the design process as possible. Applying FM expertise to early design decisions helps address multiple post-occupancy problems, including a lack of operability, maintainability, and serviceability. FM involvement in early design decisions also promotes buildings that are better suited to owners' needs; more attractive; easier to commission and maintain; easier to manage; more cost effective to operate and construct; and better able to address occupant needs.

The literature review further surveyed the domain of facility management and found widespread consensus regarding its multi-faceted nature. Modern facility management is not limited to the operation and maintenance of a facility. Instead, it is also concerned with strategic planning and user experiences. Furthermore, while the role of facility management should not be confused with that of design, FMs are strategically positioned to play an important role in facility design. Additionally, FMs have the impetus to increase their involvement in design as modern buildings often experience performance gaps between anticipated and actual operational performance, a gap often blamed on FMs.

The involvement of FMs in early design is found to be important for two reasons: 1) operational difficulties are often caused by design faults rather than faults in construction, and 2) the effects of early design decisions have been shown to have far-reaching impacts on the functionality, operation, and maintenance of built assets – particularly with regards to cost. This research documents the value of FM involvement in AE-design. This is used as a point of departure to support the need for strategic FM-design knowledge sharing frameworks and associated solutions that support AE-design processes.

9.2.2 Objective 1

Identify barriers to sharing facility management and operations information and knowledge with AE-design teams.

The first objective was addressed through both the literature review and the data gathering – semi-structured interviews, online questionnaires, and validation interviews. The literature review found that despite the demonstrated benefits of FM involvement in AE-design, persistent barriers limit FM information and knowledge sharing with AE-design. Furthermore, incentives to support such knowledge sharing are lacking. Existing research identifies a range of barriers to integrating FM/O operations knowledge into AE-design processes, including:

1. Lack of resources and mechanisms/tools
2. Lack of knowledge management or classification
3. Knowledge gaps
4. Nature of design process
5. Lack of priority or Incentive

Information gathered in the data collection stages of this research supported the findings from the literature review. Furthermore, this thesis found the following factors act as additional barriers limiting the sharing of existing facility management and operations knowledge and information with AE-design decision-making processes:

1. a lack of sufficient technical skills of AE and FM professionals,
2. a lack of time available during a project,
3. data, information, and knowledge are not stored in a manner that is easy to find or share between disciplines, and
4. a lack of appropriate methods and mechanisms to facilitate knowledge sharing.

9.2.3 Objective 2

To identify what information is available from facility management and operations to support AE-design decision-making process.

The second objective was primarily addressed through the semi-structured interviews and data collected through an online questionnaire. The objective was thus fulfilled through the data collection phase of the thesis. While this objective was not addressed conclusively, the author advocates that the objective is successfully fulfilled based on the data and information collected from the research.

Data collected through the literature review, interviews, and questionnaire reveal there was a recognised benefit to FM involvement in the AE-design process; however, there was no definitive answer as to what information would be beneficial to share between FM and AE-design teams. This result was not surprising as projects are unique and have unique requirements. However, common themes were evident in responses to the interviews and questionnaires which lead to the development of a standard classification system to link data from a range of sources, such as project requirements, FM related data, external data, and AE-design-related data.

A thematic analysis of the interviews and questionnaires found the following themes regarding what information would be most helpful to share between FM and AE-design:

1. information related to standard operations and maintenance procedures to be performed once the facility is in operation;
2. space and occupancy use of existing or similar facilities;
3. historic records associated with maintenance and utility costs;
4. knowledge and skill set of FM/O staff; and
5. internal specifications, such as for materials, equipment, furniture systems.

These themes were important in the context of this research as they formed the basis of the proposed conceptual framework, which fulfilled Objective 4.

In addition, this research revealed that AE and FM respondents had similar views regarding what information and data from FM was most valuable to provide to AE-design teams.

However, there was some disparity between FM and AE respondents when it came to the value of data and information associated with operational costs. FM respondents weighed the value of information related to operational and maintenance costs (life cycle costs) as more significant than AE respondents. In contrast, both AE and FM respondents saw information related to *occupancy use*, *user satisfaction,* and *energy use* as valuable.

9.2.4 Objective 3

To identify how facility management and operations information and knowledge can be shared with AE-design teams.

The third objective was primarily addressed through the semi-structured interviews and online questionnaire. While this objective was not addressed conclusively, as every project or design firm is somewhat unique, the author advocates that the objective is successfully fulfilled based on the data and information collected.

Information and data gathered through this research revealed there is no definitive answer as to how facility management and operations knowledge, information, and data can best be shared with AE-design teams. However, this research found a reliance on text-based documents (such as emails and meeting minutes) and handwritten notes for documenting decision-making processes within AE and FM/O teams. In the context of this research and the proposed DDSS, this appeared to be a fundamental aspect of current practices within the pool of respondents.

Almost half (45%) of US AE-FM respondents indicated they did not maintain a formal record (database) of lessons learned from past projects or were unaware if they did. This lack of record keeping was noteworthy in the context of this research because if lessons learned from past projects are not maintained in an easily accessible manner, it is challenging to apply those lessons to future projects. Additionally, responses indicated lessons learned were often maintained as implicit knowledge within the minds of individual employees. This reliance on implicit knowledge presented several problems in the context of this research. Implicit knowledge is not easily made searchable or able to be applied to different projects outside of the mind of the individual who holds the knowledge. Furthermore, implicit knowledge is often lost when individuals change jobs, switch positions, or retire. To some degree, the over-reliance on implicit knowledge in the AE-design process, and lack of interactions between FM and AE-design, is that which this research seeks to address.

The data gathered also suggested that the digital exchange of information and knowledge from FM to AE-design would also require some face-to-face interaction to interpret the information. At the onset of this research project, the researcher anticipated developing a digital tool to facilitate the transfer of information between FM and AE in place of in-person interactions. However, data gathered through the interview process and questionnaire suggested a digital tool by itself would be insufficient, and the proposed framework, therefore, accommodates both digital and interpersonal exchanges between FM and AE.

The data collected from the research showed that it was clear that both FM and AE professionals stored data and information in a range of forms. Therefore, the solution proposed to fulfil the research aim accommodates a range of information types and storage mechanisms. Furthermore, the data showed that any digital data transfer needs in-person interactions at specific points to explain the data and must also fit within existing workflows.

9.2.5 Objective 4

To develop and validate a conceptual framework that supports AE-design decisions by facilitating information and knowledge sharing between facility management and operations and AE-design teams.

The fourth objective was fulfilled through the development of the proposed framework (conceptualised as a DDSS in this thesis). While the framework does not directly enforce the involvement of FM/O knowledge in AE-design processes, it contains mechanisms that nudge AE-design teams and FM/O to increase their knowledge sharing and information transfer.

The framework contains multiple subsystems (referred to as DDSTs): a data store; a series of checklists which link the data needs of AE-design teams with FM/O data records; a DDST which links design decisions, project requirements, decision support data, and decision rationale with BPM design objects; and decision and data trees which make design decisions and their related data visible in non-model views. This conceptual DDSS framework and conceptual DDSTs fulfil Objective 4.

9.3 Contribution to Knowledge

The knowledge contribution of this research includes the articulation of a DDSS framework and conceptual DDSTs that facilitate information sharing between FM/O and AE-design teams. The main contributions of this research concerning both academic research and professional practice are presented in this section.

9.3.1.1 Academic Contribution to Knowledge

Prior research has identified the benefits of, barriers to, and conceptual proposals for sharing information and knowledge between FM/O and AE. This research reaffirmed much of the prior research in this area and validated it by reaching similar conclusions. Data collected through the research process – semi-structured interviews, online questionnaires, and validation interviews – also add to the understanding of barriers currently limiting FM input during AE-design processes. This validation of existing research and additional elaboration of barriers represents a contribution to knowledge.

9.3.1.2 Practice Contribution to Knowledge

The literature review identified persistent gaps in tools and methods necessary to share information and knowledge between FM and design teams effectively. The knowledge contribution of this research further includes the articulation of a DDSS framework and proof of concept DDSTs that facilitate information sharing between FM/O and AE-design teams. This framework and associated tools create project value by enhancing FM/O – AE information transfer and improve design decision-making processes by enabling the transfer of structured, accurate, relevant, and timely information at the appropriate stages of the design process. Improving design decision-making processes is expected to improve the overall quality of the built environment.

9.4 Future Work

Throughout the process of completing this research project, multiple new questions arose that could not be addressed in the context of a single thesis or single research project. In some instances, these questions represent areas of potential future work. These additional research questions were identified and discussed throughout the thesis and are summarised again in the sub-sections below. Also, the DDSS framework and associated DDSTs presented in this thesis were presented as conceptual proofs-of-concept only and were not presented as fully functioning artefacts. Instead, they are intended to provide the foundation for future research that develops fully functioning digital applications.

9.4.1 Data Store

The DDSS – Decision Model, includes a proposed data store which houses the associated data and information. Files, data, and information are filtered and organised according to the proposed classification system, as well as any additional classification systems utilised on a project (such as MasterFormat). This data store, as presented, is primarily populated with information and data from previous project decision models, a project's requirement model, external data associated with AE-design and construction, and FM/O related data. However, while this study is focused on information that comes from FM/O, it could likewise come from building regulations, general knowledge, designers experience, professional bodies of knowledge, or reference standards.

It is recognised that the use of the proposed data store presents a range of privacy and intellectual property issues; however, the researcher is confident that these issues can be resolved and are beyond the scope of this thesis.

9.4.2 Potential DDSS Interface with Building Product Model

The development of a fully functioning BPM decision capture is beyond the scope of the thesis research question. While Section 7.8.5 describes a conceptual understanding of how a BPM decision capture tool might function, it is presented in concept only and represents an area of potential future research.

9.4.3 Decision and Data Tree Diagrams

Within the DDSS – Decision Model, data and design decision tree diagrams are proposed to 1) graphically visualise the data and information available and used within the proposed decision model, and 2) to graphically visualise, outside the context of the BPM, design decisions made and links to their supporting documentation. In this manner, it is possible for designers to easily see what data and information are available to them (related to a particular design decision) as organised according to the proposed classification system. Also, once a design decision is made and documented, it would be possible to graphically see each crucial decision and the rationale and documentation which underpins that decision. Furthermore, design decisions can be viewed within the context of which project requirements they address, and inversely, project requirements can be used to filter what design decisions relate to each requirement.

The development of a fully functioning decision tree is beyond the scope of this thesis. While Section 7.8.6 describes a conceptual understanding of how these decision diagrams might function, this work is seen as an area of future research.

9.4.4 Additional Research Opportunities

The data analysis discussed in Chapters 5, Chapter 6, and the literature review in Chapter 2 identifies multiple barriers which hinder information and knowledge sharing between FM and AE-design. The author proposed in Chapter 2 that these barriers to AE-FM/O knowledge sharing could be categorised as stemming from four factors: 1) a lack of resources, 2) a knowledge gap, including a lack of awareness, 3) the nature of the design process, or 4) a lack of priority or incentive. This thesis was primarily focused on addressing the first two. The lack of incentive and fundamental nature of the AE building design process was beyond the scope of this thesis and represents an area of potential future research.

Furthermore, because the proposed DDSS (Decision Model and associated DDSTs) sought, in part, to link project requirements with FM/O expertise and AE-design decisions, it was necessary to develop a classification system that could bridge the gap between these domains. That is to say, it was necessary to develop a classification system that can connect critical design decisions with BPM design objects, project requirements, and FM/O information and knowledge. It must also link a range of external knowledge sources and types, but the focus of this thesis was on FM/O data. The linking of other knowledge sources represents an area of potential future research.

9.5 Conclusion

This research aimed to facilitate knowledge sharing between FM and AE-deign to support design decision-making processes. The study began with the intent to develop a digital, possibly BIM integrated, tool to facilitate the sharing of existing FM/O information, and knowledge with AE-design teams. However, over the course of the research project, it became evident that the sole reliance on the digital transfer of information, or a singularly BIM integrated tool, was insufficient to fulfil the intended aim. The data collected suggested that knowledge sharing between FM and AE-design was more complex than anticipated and was not supported by current digital AE knowledge structuring mechanisms. This suggested the continual benefits of personal interaction. In the future, the framework may be further developed into a fully functioning digital artefact. However, the development of new computer strategies and potentially new or expanded programming languages considered necessary for this to happen was seen as beyond the scope of this work.

The research findings led to developing a hybrid framework that facilitates the sharing of digital information between FM/O and AE-design while providing context and knowledge sharing through in-person interactions. It further establishes a structure for these interactions and provides time and space for them to occur within the design development process. In this manner, the proposed framework and associated *FM Basis of Design* keep with the suggestion of Çıdık and Boyd (2020) that design requires enabling structures to promote interactions between stakeholders (for example, between FMs and AE designers). The framework also helps establish a "shared sense of purposefulness" between AE designers and FMs (Çıdık & Boyd, 2020).

By establishing a series of dialogue meetings between FM and AE (Støre-Valen, 2021), the framework further accommodates both knowledge pushes and knowledge pulls between FM and AE, as described by Jensen et al. (2019). The framework structure and associated support tools allow AE to request (pull) information and FM/O to provide (push) information to AE, and vice versa, throughout the design process.

The proposed framework acts as a bottom-up approach to address knowledge and information sharing between FM and AE (Papanek, 1985). It seeks to develop a system that works within the research scope and the communities of practice involved in the data collection. Research completed with a different scope or within other communities of practice may have resulted in different conclusions. And while the proposed framework, and associated research, reference BIM and act as an overlay with BIM, it is not predefined by existing paradigms such as BIM. This is because BIM is structured around identifying model objects, where this work focuses on broader concepts of knowledge. And while some of the focus of this research relates to design objects and model objects, other areas of the research focus on general concepts and abstract ideas. Furthermore, even though the study is situated within the built environment domain, the findings and proposals potentially have broader applications. They are therefore not seen as limited to a BIM or built environment contexts.

During the latter portion of this research, in response to the COVID-19 pandemic, the world has undergone a sudden and fundamental shift in how we communicate and conduct business. While the long-term impact of the pandemic is unknown, it sped up the transition to virtual meetings and other online methods of communication. The digital sharing of information combined with virtual meetings to discuss and explain such information is now commonplace in ways it was not pre-pandemic. This research's data collected pre-pandemic suggested that both digital transfer and in-person communication were necessary to explain transmitted information further. This hybrid approach is now more common through virtual meetings on various web-based platforms; however, even within the sudden upheaval caused by the global pandemic, the researcher advocates for the benefit of a framework such as the one presented in this research.

The contextualisation of shared knowledge and information remains essential regardless of communication methods, whether through in-person or virtual meetings. The proposed framework does not mandate a particular form of communication and works equally well in a world of virtual or in-person meetings. Changes to more frequently held virtual instead of in-person meetings due to the pandemic are seen to augment the framework and not replace its approach and design.

Ongoing advances in artificial intelligence (AI), computational design, machine learning, deep learning, and the semantic web similarly represent opportunities to support project information management and collaboration (K. Kim et al., 2018; Niknam, Jalaei, & Karshenas, 2019; Niknam & Karshenas, 2017; Ruikar, Anumba, Duke, Carrillo, & Bouchlaghem, 2007). In this capacity, their use represents additional opportunities to augment the framework proposed in this thesis. However, while such technologies may enhance information and knowledge sharing, they are still dependent on standard ontologies to link information and knowledge – such as the one included in this framework. Furthermore, while the future impact of such technology on design is unknown (see Franco, 2019, for example), design continues to remain a communal activity that involves the direct sharing of information and knowledge between stakeholders. Therefore, this thesis developed a framework that enables knowledge sharing within the research scope and the existing workflows of the associated community of practice. While AI and related technologies hold the potential to enhance and augment this work, it has not yet replaced the need to share tacit knowledge between project team individuals and project stakeholders through frameworks such as the one presented in this thesis.

It is also noted, that while the proposed framework represents a bottom-up approach for enhancing knowledge sharing between FM and AE designers, alternative top-down approaches could likewise be pursued by organisations such as the AIA, IFMA, or other international facility management organisations. For example, the AIA could work with IFMA or other organisations to influence architecture education to include an FM component within accredited architectural degree programs or add FM components to continuing education requirements. Additionally, the body of knowledge held within organisations such as IFMA and their members represent a breadth of knowledge regarding the outcomes of building design decisions. This body of knowledge represents an opportunity for IFMA, or similar organisations, to redefine the role of FM to include design support, conduct design research, or to act as a depository of lessons learned across a range of facility types. Additionally, other researchers have recommended top-down proposals for FM involvement with AE-design; for example, suggestions that FMs should be contractually required to participate in the design process, awareness of FM value in design should be increased, or FM competencies should be improved (Section 2.4). Such proposals are seen as top-down and would require the work and effort of a professional organisation such as IFMA, for example, to work with the AIA to provide a role for FM in standard AIA documents and contracts. Such top-down approaches were therefore not pursued within the scope of this thesis; however, this is not seen as diminishing their potential.

When this study started, the researcher was a licensed architect who taught in an architectural design and facility management degree program at a public university in the United States. Throughout the thesis, it became clear to the researcher, in his prior role as a practising architect, how little he fully understood or was fully aware of what happened in a facility after it was designed and constructed, this despite a professional career focused on the design of governmental facilities, which routinely included the involvement of facility managers in the design process. As a result of the research and the scientific method it followed, the researcher views himself as a better architect and more aware of users’ and stakeholders’ needs.

At the end of the thesis, the author no longer teaches architectural design. While still a licensed architect, he finds himself working internationally as a facility manager for an organisation with facilities in approximately 160 countries and more than 250 locations worldwide. While this does not change the focus of the research, it does represent the fluid, back and forth nature of the bodies of knowledge between the AE and FM professions. Recognising the fluid nature of built environment knowledge and the common overlap of knowledge between professions such as FM and AE-design, despite persistent barriers limiting knowledge sharing, this thesis seeks to enhance AE-design decision-making processes by offering solutions to support FM involvement with the AE-design process.

REFERENCES

Ackoff, R. L. (1989). From data to wisdom. *Journal of Applied Systems Analysis, 16*(1), 3-9.

Adams, J., Khan, H. T., Raeside, R., & White, D. I. (2007). *Research methods for graduate business and social science students*: Sage Publications India.

Ahmed-Kristensen, S., & Vianello, G. (2015). A model for reusing service knowledge based on an empirical case. *Research in Engineering Design, 26*(1), 57-76.

Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of big data in facilities management: Opportunities and challenges. *Facilities, 35*(13/14), 725-745. doi:https://doi.org/10.1108/F-06-2016-0064

Aken, J. E. (2004). Management research based on the paradigm of the design sciences: The quest for field-tested and grounded technological rules. *Journal of Management Studies, 41*(2), 219-246.

Al-Kasasbeh, M., Abudayyeh, O., & Liu, H. (2021). An integrated decision support system for building asset management based on BIM and work breakdown structure. *Journal of Building Engineering, 34*(2021), 101959. doi:https://doi.org/10.1016/j.jobe.2020.101959

Alavi, M., & Leidner, D. E. (2001). Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Quarterly*, 107-136.

Alexander, C. (1964). *Notes on the synthesis of form* (Vol. 5): Harvard University Press.

Alexander, C. (1984). The state of the art in design methods. In N. Cross (Ed.), *Developments in design methodology*: Wiley.

Alexander, K. (2013). *Facilities management: Theory and practice*. London: Routledge.

AllAssignmentHelpUK. (2017). Research onion – made easy to understand and follow. *Best Articles.* Retrieved from https://www.allassignmenthelp.co.uk/blog/research-onion-made-easy-to-understand-and-follow/

Alvesson, M., & Kärreman, D. (2001). Odd couple: Making sense of the curious concept of knowledge management. *Journal of Management Studies, 38*(7), 995-1018.

Alwan, Z., & Gledson, B. J. (2015). Towards green building performance evaluation using asset information modelling. *Built Environment Project and Asset Management, 5*(3), 290-303.

Ammar-Khodja, S., & Bernard, A. (2008). An overview on knowledge management. In *Methods and tools for effective knowledge life-cycle-management* (pp. 3-21): Springer.

Anh Thi Lê, M., & Brønn, C. (2007). Linking experience and learning: Application to multi-project building environments. *Engineering, Construction and Architectural Management, 14*(2), 150-163. doi:10.1108/09699980710731272

Arditi, D., & Nawakorawit, M. (1999). Designing buildings for maintenance: Designers' perspective. *Journal of Architectural Engineering, 5*(4), 107-116. doi:10.1061/(asce)1076-0431(1999)5:4(107)

Arnott, D., & Pervan, G. (2005). A critical analysis of decision support systems research. *Journal of Information Technology, 20*(2), 67-87.

Arroyo, P., Mourgues, C., Flager, F., & Correa, M. G. (2018). A new method for applying choosing by advantages (CBA) multicriteria decision to a large number of design alternatives. *Energy and Buildings, 167*(2018), 30-37.

Asimow, M. (1962). *Introduction to design*: Prentice-Hall.

Atsrim, F., Buertey, J. I. T., & Boateng, K. (2015). Managing the design process in the construction industry: A literature review. *Architecture Research, 5*(1), 16-30.

Baldauf, J. P., Formoso, C. T., Tzortzopoulos, P., Miron, L. I., & Soliman-Junior, J. (2020). Using building information modelling to manage client requirements in social housing projects. *Sustainability, 12*(7), 2804.

Baruch, Y., & Holtom, B. C. (2008). Survey response rate levels and trends in organizational research. *Human Relations, 61*(8), 1139-1160.

Becker, F., & Steele, F. (1990). The total workplace. *Facilities, 8*(3), 9-14. doi:10.1108/eum0000000002099

Best, R., Langston, C., & Valence, G. (2018). *Workplace strategies and facilities management: Building in value*: Routledge.

BIFM. (n.d.). Facilities management introduction. Retrieved from http://www.bifm.org.uk/bifm/about/facilities/

Boecker, J., Horst, S., Keiter, T., Lau, A., Sheffer, M., Toevs, B., & Reed, B. (2009). *The integrative design guide to green building: Redefining the practice of sustainability*: Wiley.

Boge, K., Salaj, A., Bjørberg, S., & Larssen, A. K. (2018). Failing to plan–planning to fail. *Facilities, 36*(1/2), 49-75. doi:https://doi.org/10.1108/F-03-2017-0039

Bounded rationality. (2012). In N. M. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 481-482). Boston, MA: Springer US.

Braha, D., & Maimon, O. (1997). The design process: Properties, paradigms, and structure. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 27*(2), 146-166. doi:10.1109/3468.554679

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. doi:10.1191/1478088706qp063oa

Breen, G. E., Breen, G., Dutka, A., & Alan, D. (1998). *State of the art marketing research*: McGraw Hill Professional.

Brelade, S., & Harman, C. (2003). *Practical guide to knowledge management*: Thorogood.

Bröchner, J. (1996). Feedback from facilities management to design and construction-systems issues. *The Organization and Management of Construction: Shaping Theory and Practice, 3*, 238-246.

Bröchner, J. (2003). Integrated development of facilities design and services. *Journal of Performance of Constructed Facilities, 17*(1), 19-23. doi:10.1061/(asce)0887-3828(2003)17:1(19)

Bröchner, J. (2010). Innovation and ancient Roman facilities management. *Journal of Facilities Management, 8*(4), 246-255. doi:10.1108/14725961011078963

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues, 8*(2), 5–21.

Buchanan, R. (2001). Design research and the new learning. *Design Issues, 17*(4), 3-23. doi:10.1162/07479360152681056

Buchanan, R., & Margolin, V. (1995). Discovering design: Explorations in design studies. In. Chicago: University of Chicago Press.

Caixeta, M. C. B. F., Tzortzopoulos, P., & Fabricio, M. M. (2019). User involvement in building design–a state-of-the-art review. *Pós. Revista do Programa de Pós-Graduação em Arquitetura e Urbanismo da FAUUSP, 26*(48), e151752-e151752.

Chandra, V., & Loosemore, M. (2011). Communicating about organizational culture in the briefing process: Case study of a hospital project. *Construction Management and Economics, 29*(3), 223-231. doi:10.1080/01446193.2010.521756

Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F., & Gao, W. (2013). The evolution, challenges, and future of knowledge representation in product design systems. *Computer-Aided Design, 45*(2), 204-228. doi:10.1016/j.cad.2012.08.006

Chew, M. Y. L., Conejos, S., & Asmone, A. S. (2017). Developing a research framework for the green maintainability of buildings. *Facilities, 35*(1/2), 39-63. doi:10.1108/f-08-2015-0059

Chew, M. Y. L., Tan, S. S., & Kang, K. H. (2004). Building maintainability—review of state of the art. *Journal of Architectural Engineering, 10*(3), 80-87. doi:10.1061/(asce)1076-0431(2004)10:3(80)

Chodasova, Z. U. Z. A. N. A. (2004). Facility management in development process. *Economics and Business Management, 2*(6), 52-60.

Chong, W.-K., & Low, S.-P. (2006). Latent building defects: Causes and design strategies to prevent them. *Journal of Performance of Constructed Facilities, 20*(3), 213-221.

Chotipanich, S. (2004). Positioning facility management. *Facilities, 22*(13/14), 364-372. doi:10.1108/02632770410563086

Churchman, C. W. (1967). Guest editorial: Wicked problems. *Management Science, 14*(4), B141-B142.

Chynoweth, P. (2009). The built environment interdiscipline: A theoretical model for decision makers in research and teaching. *Structural Survey, 27*(4), 301-310. doi:https://doi.org/10.1108/02630800910985090

Çıdık, M. S., & Boyd, D. (2020). "Shared sense of purposefulness": A new concept to understand the practice of coordinating design in construction. *Construction Management and Economics, 38*(1), 18-31.

Coates, S. P., Arayici, Y., Koskela, L. J., Kagioglou, M., Usher, C., & O' Reilly, K. (2010). *The limitations of BIM in the architectural process*. Paper presented at the First International Conference on Sustainable Urbanization (ICSU), Hong Kong.

Codinhoto, R. (2019). Building information modelling. In *Modern building design: Evidencing changes in engineering and design practice*: The Crowood Press.

Codinhoto, R., Donato, V., Comlay, J., Adeyeye, K., & Kiviniemi, A. (2018). BIM FM: An international call for action. In *Contemporary strategies and approaches in 3-d information modeling* (pp. 83-114): IGI Global.

Codinhoto, R., & Lo, S. (2019). Place-making and well being. In R. Codinhoto (Ed.), *Modern building design: Evidencing changes in engineering and design practice*: The Crowood Press.

Coleman, T. F. (1996). *The minnesota income tax compliance experiment state tax results*. Retrieved from http://www.state.mn.us/legal_policy/research_reports/content/complnce.pdf

Collins, H. (2019). *Creative research: The theory and practice of research for the creative industries* (Second edition. ed.). London: Bloomsbury Visual Arts.

Collis, J., Hussey, R., & Hussey, J. (2003). *Business research: A practical guide for undergraduate and postgraduate students* (2nd ed. ed.). Basingstoke: Palgrave Macmillan.

Conteh, N. Y., & Forgionne, G. (2005). A just-in-time approach to intelligent decision support systems. *Journal of Decision Systems, 14*(1-2), 39-54.

Conteh, N. Y., & Forgionne, G. A. (2006). A simulation study of just-in-time knowledge management (JITKM). In *Intelligent decision-making support systems* (pp. 187-197): Springer.

Cooper, H. (2015). *Research synthesis and meta-analysis: A step-by-step approach* (Vol. 2): Sage Publications.

Creswell, J. W. (2014). *Research design qualitative, quantitative, and mixed methods approaches*. Los Angeles: Sage Publications.

Creswell, J. W., & Clark, V. L. P. (2011). *Designing and conducting mixed methods research*: Sage Publications.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.): Sage Publications.

Cross, N. (1990). The nature and nurture of design ability. *Design Studies, 11*(3), 127-140.

Cross, N. (2001). Designerly ways of knowing: Design discipline versus design science. *Design Issues, 17*(3), 49-55.

Cross, N. (2006). *Designerly ways of knowing*. London: Springer.

Cross, N. (2007). Forty years of design research. *Design Studies, 28*(1), 1-4. doi:10.1016/j.destud.2006.11.004

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. London: Sage Publications.

CSI. (2017). About omniclass. Retrieved from https://www.csiresources.org/standards/omniclass/standards-omniclass-about

D'Alfonso, S. (2013). The logic of knowledge and the flow of information. *Minds and Machines, 24*(3), 307-325. doi:10.1007/s11023-013-9310-x

Dave, B., & Koskela, L. (2009). Collaborative knowledge management—a construction case study. *Automation in Construction, 18*(7), 894-902.

Davenport, T. H., De Long, D. W., & Beers, M. C. (1998). Successful knowledge management projects. *MIT Sloan Management Review, 39*(2), 43.

Dean, J., James W, & Sharfman, M. P. (1996). Does decision process matter? A study of strategic decision-making effectiveness. *Academy of Management Journal, 39*(2), 368-392.

Denzin, N. K., & Lincoln, Y. S. (2018). *The sage handbook of qualitative research* (5th ed.): Sage Publications.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2013). *Strategies of qualitative inquiry* (Fourth edition. ed.). Los Angeles: Sage Publications.

Designing in the human context. (2012). Retrieved from https://www.seas.harvard.edu/news/2012/01/designing-human-context

Dickson, M. (2004). Achieving quality in building design by intention. In *Designing better buildings: Quality and value in the built environment* (pp. 205-214): Routledge.

Dilnot, C. (2018). Thinking design: A personal perspective on the development of the design research society. *Design Studies, 54*, 142-145. doi:10.1016/j.destud.2017.11.002

Dixit, M. K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F., & Lavy, S. (2019). Integration of facility management and building information modeling (BIM). *Facilities, 37*(7/8), 455-483. doi:10.1108/f-03-2018-0043

Dorst, K., & Lawson, B. (2013). *Design expertise*: Routledge.

Dresch, A., Lacerda, D. P., & Antunes, J. A. V. (2015). Design science research. In *Design science research* (pp. 67-102): Springer.

Dunston, P. S., & Williamson, C. E. (1999). Incorporating maintainability in constructability review process. *Journal of Management in Engineering, 15*(5), 56-60. doi:10.1061/(asce)0742-597x(1999)15:5(56)

Easterby-Smith, M., & Lyles, M. A. (2011). *Handbook of organizational learning and knowledge management* (2nd ed.): Wiley.

Eastman, C. M. (1999). *Building product models: Computer environments supporting design and construction*. Boca Raton, FL: CRC Press.

Eastman, C. M. (2011). *BIM handbook: A guide to building information modeling for owners, managers designers, engineers, and contractors* (2nd ed.). Hoboken, NJ: Wiley.

Edirisinghe, R., London, K. A., Kalutara, P., & Aranda-Mena, G. (2017). Building information modelling for facility management: Are we there yet? *Engineering, Construction and Architectural Management, 24*(6), 1119-1154. doi:10.1108/ecam-06-2016-0139

Edum-Fotwe, F. T., Egbu, C., & Gibb, A. (2003). Designing facilities management needs into infrastructure projects: Case from a major hospital. *Journal of Performance of Constructed Facilities, 17*(1), 43-50.

Elo, S., & Kyngas, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing, 62*(1), 107-115. doi:10.1111/j.1365-2648.2007.04569.x

Emmitt, S. (2007). *Design management for architects*. Oxford: Blackwell.

Engelbart, D. C. (1962). *Augmenting human intellect: A conceptual framework*. Menlo Park, CA.

Erdener, E. (2003). Linking programming and design with facilities management. *Journal of Performance of Constructed Facilities, 17*(1), 4-8. doi:10.1061/(asce)0887-3828(2003)17:1(4)

Ergen, E., Kula, B., Guven, G., & Artan, D. (2021). Formalization of occupant feedback and integration with BIM in office buildings. *Journal of Computing in Civil Engineering, 35*(1), 04020055.

Estates, N. (1996). *Re-engineering the facilities management service*. Health Facilities Note, (16).

Fatayer, F. A. (2012). *A framework for the involvement of the maintenance manager during the design development and review stages.* (PhD), King Fahd University of Petroleum and Minerals, Saudi Arabia.

Fatayer, F. A., Hassanain, M. A., Abdallah, A., & Al-Hammad, A. M. (2019). Investigation of facilities management practices for providing feedback during the design development and review stages. *International Journal of Building Pathology and Adaptation, 37*(5), 597-614. doi:https://doi.org/10.1108/IJBPA-05-2018-0040

Fichter, D. (2009). What is a mashup. *Library Mashups. Exploring new ways to deliver library data. Medford, NJ: Information Today, Inc*.

Finch, E., & Zhang, X. (2013). Facilities management. In R. Yao (Ed.), *Design and management of sustainable built environments* (pp. 305-326). London: Springer London.

Forsyth, A., & Crewe, K. (2006). Research in environmental design: Definitions and limits. *Journal of Architectural and Planning Research, 23*(2), 160-175.

Forza, C. (2002). Survey research in operations management: A process-based perspective. *International Journal of Operations & Production Management, 22*(2), 152-194. doi:https://doi.org/10.1108/01443570210414310

Franco, J. T. (2019, 06/20/2019). Adaptative plans: An algorithm that predicts spatial configurations. Retrieved from https://www.archdaily.com/919339/adaptative-plans-are-here-an-algorithm-that-predicts-spatial-configurations?ad_medium=widget&ad_name=chrome-extension

Freeman, P., & Hart, D. (2004). A science of design for software-intensive systems. *Communications of the ACM, 47*(8), 19-21. doi:10.1145/1012037.1012054

Freund, R. J., Mohr, D. L., & Wilson, W. J. (2010). *Statistical methods* (3rd ed.): Elsevier.

Galle, P. (2016). Self-knowledge by proxy: Parsons on philosophy of design and the modernist vision. *She Ji: The Journal of Design, Economics, and Innovation, 2*(4), 322-342. doi:10.1016/j.sheji.2017.05.001

Garner, S. W., & Evans, C. (2012). *Design and designing: A critical introduction* (English ed.). London: Berg.

Gasparski, W., & Strzalecki, A. (1990). Contributions to design science: Praxeological perspective. *Design Methods and Theories, 24*(2), 3.

GCR, N. (2004). Cost analysis of inadequate interoperability in the US capital facilities industry. *National Institute of Standards and Technology (NIST)*, 223-253.

Gelder, J., Tebbit, J., Wiggett, D., & Mordue, S. (2013). *BIM for the terrified a guide for manufacturers* (978-1-909415-03-4). Retrieved from London: https://www.thenbs.com/knowledge/bim-for-the-terrified

Gill, J., & Johnson, P. (2002). *Research methods for managers* (3rd ed. ed.). London: Sage Publications.

Göçer, Ö., Hua, Y., & Göçer, K. (2015). Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance. *Building and Environment, 89*, 14-27. doi:10.1016/j.buildenv.2015.02.011

Gold, A. H., Malhotra, A., & Segars, A. H. (2001). Knowledge management: An organizational capabilities perspective. *Journal of Management Information Systems, 18*(1), 185-214.

Gregory, S. A. (Ed.) (1966). *The design method*. Boston, MA: Springer, US.

Griffiths, R. (2004). Knowledge production and the research–teaching nexus: The case of the built environment disciplines. *Studies in Higher Education, 29*(6), 709-726.

Grimshaw, R., & Keeffe, G. (1993). Facilities management: The potential for research. In *Facilities management: Research directions*: RICS Books.

Groat, L. N., & Wang, D. (2013). *Architectural research methods* (2nd ed.): Wiley.

GSA. (2007). *GSA building information modeling guise series 01—overview*. Retrieved from Washington, DC, USA: https://www.gsa.gov/cdnstatic/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59-82.

Hack, G. (1984). Research for urban design. In J. Snyder (Ed.), *Architectural research* (pp. 125-145). New York: Van Nostrand Reinhold.

Han, S.-Y., & Kim, T. J. (1989). Can expert systems help with planning? *Journal of the American Planning Association, 55*(3), 296-308.

Hardin, B. (2009). *BIM and construction management: Proven tools, methods, and workflows*: Wiley.

Harputlugil, T. (2018). Analytic hierarchy process (AHP) as an assessment approach for architectural design: Case study of architectural design studio. *ICONARP International Journal Of Architecture And Planning, 6*(2), 217-245. doi:10.15320/iconarp.2018.53

Hassanain, M. A., Al-Hammad, A. M., & Fatayer, F. A. (2014a). Assessment of architectural defects attributed to lack of maintenance feedback to the design team. *Architectural Science Review, 57*(2), 132-138.

Hassanain, M. A., Al-Hammad, A. M., & Fatayer, F. A. (2014b). Assessment of defects in HVAC systems caused by lack of maintenance feedback to the design team. *Architectural Science Review, 57*(3), 188-195.

Hassanain, M. A., Fatayer, F. A., & Al-Hammad, A. M. (2015). Design phase maintenance checklist for water supply and drainage systems. *Journal of Performance of Constructed Facilities, 29*(3), 04014082.

Hassanain, M. A., Fatayer, F. A., & Al-Hammad, A. M. (2016). Design-phase maintenance checklist for electrical systems. *Journal of Performance of Constructed Facilities, 30*(2), 06015003. doi:https://doi.org/10.1061/(ASCE)CF.1943-5509.0000774

Hayes, R. L. (2014). *The architect's handbook of professional practice* (15th ed.): Wiley.

Hen, N. W., Sarpin, N., Omar, R., Wee, S. T., & Chen, G. K. (2021). Integration of facilities management considerations in design stage of construction project. *Research in Management of Technology and Business, 2*(1), 850-864.

Heron, J. (1996). *Co-operative inquiry: Research into the human condition*: Sage Publications.

Hevner, March, Park, & Ram. (2004). Design science in information systems research. *MIS Quarterly, 28*(1), 75-105. doi:10.2307/25148625

Hinks, J., & McNay, P. (1999). The creation of a management-by-variance tool for facilities management performance assessment. *Facilities, 17*(1/2), 31-53. doi:10.1108/02632779910248893

Ho, S. P., Tserng, H. P., & Jan, S. H. (2013). Enhancing knowledge sharing management using BIM technology in construction. *Scientific World Journal, 2013*, 170498-170410. doi:10.1155/2013/170498

Hocking, V. T., Brown, V. A., & Harris, J. A. (2015). Tackling wicked problems through collective design. *Intelligent Buildings International, 8*(1), 24-36. doi:10.1080/17508975.2015.1058743

Hughes, W., Ancell, D., Gruneberg, S., & Hirst, L. (2004). *Exposing the myth of the 1:5:200 ratio relating initial cost, maintenance and staffing costs of office buildings.* Paper presented at the Proceedings of the 20th Annual ARCOM Conference, 1-3 September.

ibuunk. (2017, May 07). The concept of 'ba'. Retrieved from https://theknowledgeexplorer.org/2017/07/05/the-concept-of-ba/

IFMA. (n.d.-a). Ifma's 11 core competencies. Retrieved from http://cdn.ifma.org/sfcdn/knowledge-base/ifmas-11-core-competencies.pdf?sfvrsn=0

IFMA. (n.d.-b). Member demographics. Retrieved from https://www.ifma.org/marketplace/promotional-opportunities/member-demographics

IFMA. (n.d.-c). What is facility management. Retrieved from https://www.ifma.org/about/what-is-facility-management

Ipsen, K. L., Pizzol, M., Birkved, M., & Amor, B. (2021). How lack of knowledge and tools hinders the eco-design of buildings—a systematic review. *Urban Science, 5*(1), 20.

Isa, N. M., Kamaruzzaman, S. N., Mohamed, O., & Berawi, M. A. (2017). Review of facilities management functions in value management practices. *International Journal of Technology, 8*(5), 830-840. doi:https://doi.org/10.14716/ijtech.v8i5.865

Islam, R., Mohamed, S. F., Bjørberg, S., Misnan, M. S., & Yusof, Z. M. (2017). Towards a framework to integrate facilities management cost effective parameters in design process. *International Journal of Engineering and Technology, 9*(6), 4515-4526.

Islam, R., Nazifa, T. H., & Mohamed, S. F. (2019). Factors influencing facilities management cost performance in building projects. *Journal of Performance of Constructed Facilities, 33*(3), 04019036.

ISO. (2017). Facility management — vocabulary. In *ISO 41011:2017* (Vol. ISO 41011:2017). Geneva: International Organization for Standardization.

ISO. (2018a). Industry foundation classes (IFC) for data sharing in the construction and facility management industries — part 1: Data schema In *ISO* (Vol. 16739-1:2018). Geneva: International Organization for Standardization.

ISO. (2018b). Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM): Information management using building information modelling. In *ISO 19650-1* (Vol. 19650-1). Geneva: International Organization for Standardization.

Ive, G. (2006). Re-examining the costs and value ratios of owning and occupying buildings. *Building Research & Information, 34*(3), 230-245. doi:10.1080/09613210600635192

Jansson, G., Schade, J., & Olofsson, T. (2013). Requirements management for the design of energy efficient buildings. *Electronic Journal of Information Technology in Construction, 18*, 321-337.

Jaunzens, D., Warriner, D., Garner, U., & Waterman, A. (2001). *Applying facilities expertise in building design*. Garston, UK: Building Research Establishment.

Jawdeh, H. B., Abudul-Malak, M., & Wood, G. (2010). *Altering design decisions to better suit facilities management processes*. Paper presented at the 10th International Conference for Enhanced Building Operations, Kuwait.

Jennex, M. E. (2015). Knowledge management. In *Wiley encyclopedia of management* (pp. 1-6).

Jensen, P. A. (2009). Design integration of facilities management: A challenge of knowledge transfer. *Architectural Engineering and Design Management, 5*(3), 124-135.

Jensen, P. A. (2012). Knowledge transfer from facilities management to building projects: A typology of transfer mechanisms. *Architectural Engineering and Design Management, 8*(3), 170-179. doi:10.1080/17452007.2012.669131

Jensen, P. A., Damgaard, T., & Kristiansen, K. (2009). *The role of facilities management in building projects.* Paper presented at the Proceedings of CIB Changing Role, Nordwijk an der See.

Jensen, P. A., Rasmussen, H. L., & Chatzilazarou, S. (2019). Knowledge transfer between building operation and building projects. *Journal of Facilities Management, 17*(2), 208-219.

Johannesson, P., & Perjons, E. (2014). *An introduction to design science*: Springer.

Kalantari, S., Shepley, M. M., Rybkowski, Z. K., & Bryant, J. (2017a). Designing for operational efficiency: Facility managers' perspectives on how their knowledge can be better incorporated during design. *Architectural Engineering and Design Management, 13*(6), 457-478.

Kalantari, S., Shepley, M. M., Rybkowski, Z. K., & Bryant, J. A. (2017). Collaboration between designers and facility managers: Comparing the United Kingdom, the United States, and the Middle East. *Facilities, 35*(9/10), 557-572. doi:10.1108/f-08-2016-0081

Kam, C. (2005). *Dynamic decision breakdown structure: Ontology, methodology, and framework for information management in support of decision-enabling tasks in the building industry*. Retrieved from Stanford: https://purl.stanford.edu/qf915fz1421

Kamaruzzaman, S. N., Myeda, N. E., Zawawi, E. M. A., & Ramli, R. M. (2018). Developing facilities management (FM) competencies for Malaysia: Reference from international practice. *Journal of Facilities Management, 16*(2), 157-174. doi:https://doi.org/10.1108/JFM-08-2017-0036

Kaplan, A. (2017). *The conduct of inquiry: Methodology for behavioural science*: Routledge.

Keen, P. G. (1980). Adaptive design for decision support systems. *ACM SIGMIS Database: the Database for Advances in Information Systems, 12*(1-2), 15-25.

Kehily, D., & Underwood, J. (2015). *Design science: Choosing an appropriate methodology for research in BIM*. Paper presented at the CITA BIM Gathering, Dublin.

Kelemen, M. (2008). An introduction to critical management research. In N. Rumens (Ed.). Los Angeles: Sage Publications.

Kerzner, H., & Kerzner, H. R. (2017). *Project management: A systems approach to planning, scheduling, and controlling*: Wiley.

Ketokivi, M., & Mantere, S. (2010). Two strategies for inductive reasoning in organizational research. *Academy of Management Review, 35*(2), 315-333. doi:10.5465/amr.2010.48463336

Kim, K., Kim, H., Kim, W., Kim, C., Kim, J., & Yu, J. (2018). Integration of IFC objects and facility management work information using semantic web. *Automation in Construction, 87*, 173-187.

Kim, T. W., Cha, S. H., & Kim, Y. (2016). A framework for evaluating user involvement methods in architectural, engineering, and construction projects. *Architectural Science Review, 59*(2), 136-147.

Kiviniemi, A. (2005). *Requirements management interface to building product models.* (PhD), Stanford University, Stanford, CA.

Kiviniemi, A., & Fischer, M. (2004). *Requirements management interface to building product models*. Stanford, CA: Stanford University.

Kleinsmann, M., & Valkenburg, R. (2008). Barriers and enablers for creating shared understanding in co-design projects. *Design Studies, 29*(4), 369-386.

Kpamma, Z. E., Adjei-Kumi, T., Ayarkwa, J., & Adinyira, E. (2017). Participatory design, wicked problems, choosing by advantages. *Engineering, Construction and Architectural Management, 24*(2), 289-307.

Kroeber, D. W., & Watson, H. J. (1987). *Computer-based information systems: A management approach*: Prentice Hall Professional Technical Reference.

Krygiel, E. (2008). Green BIM : Successful sustainable design with building information modeling. In B. Nies (Ed.). Indianapolis, IN: Wiley.

Lawson, B. (1994). *Design in mind*. Oxford: Butterworth Architecture.

Lawson, B. (2005). *How designers think: The design process demystified* (4. ed. ed.). Amsterdam: Elsevier/Architectural Press.

Lawson, B. (2018). *The design student's journey: Understanding how designers think*: Routledge.

Lee, H. W., Oh, H., Kim, Y., & Choi, K. (2015). Quantitative analysis of warnings in building information modeling (BIM). *Automation in Construction, 51*, 23-31. doi:10.1016/j.autcon.2014.12.007

Lewin, K. (1947). Frontiers in group dynamics: II. Channels of group life; social planning and action research. *Human Relations, 1*(2), 143-153.

Liew, A. (2007). Understanding data, information, knowledge and their inter-relationships. *Journal of Knowledge Management Practice, 8*(2), 1-16.

Liew, A. (2013). DIKIW: Data, information, knowledge, intelligence, wisdom and their interrelationships. *Business Management Dynamics, 2*(10), 49.

Lin, Y. C. (2014). Construction 3D BIM-based knowledge management system: A case study. *Journal of Civil Engineering and Management, 20*(2), 186-200.

Liu, R., & Issa, R. A. (2016). Survey: Common knowledge in BIM for facility maintenance. *Journal of Performance of Constructed Facilities, 30*(3), 04015033.

Liu, R., Lavy, S., & R.A. Issa, R. (2014). Design for maintenance accessibility using BIM tools. *Facilities, 32*(3/4), 153-159. doi:10.1108/f-09-2011-0078

Loosemore, M., & Chandra, V. (2012). Learning through briefing: For strategic facilities management in the health sector. *Built Environment Project and Asset Management, 2*(1), 103-117.

Love, T. (2000). Philosophy of design: A meta-theoretical structure for design theory. *Design Studies, 21*(3), 293-313. doi:10.1016/s0142-694x(99)00012-5

Luck, R. (2012). 'Doing designing': On the practical analysis of design in practice. *Design Studies, 33*(6), 521-529.

Lützkendorf, T., Speer, T., Szigeti, F., Davis, G., Le Roux, P., Kato, A., & Tsunekawa, K. (2005). A comparison of international classifications for performance requirements and building performance categories used in evaluation methods. In P. H. Enthalten (Ed.), *11th joint CIB international symposium combining forces - advancing facilities management and construction through innovation* (Vol. V, pp. 61-80). Helsinki: Technical Research Centre of Finland.

Maher, M. L., & Gero, J. S. (2012). Design science. In W. S. Bainbridge (Ed.), *Leadership in science and technology: A reference handbook* (pp. 114–122). Thousand Oaks, CA: Sage Publications.

Markus, M. L., Majchrzak, A., & Gasser, L. (2002). A design theory for systems that support emergent knowledge processes. *MIS Quarterly, 26*(3), 179-212.

MasterFormat. (2021, Feb. 08). Masterformat. Retrieved from https://www.designingbuildings.co.uk/wiki/MasterFormat

May, M., & Williams, G. (2017). *The facility manager's guide to information technology*: International Facility Management Association.

McDermott, R. (1999). Why information technology inspired but cannot deliver knowledge management. *California Management Review, 41*(4), 103-117.

McPartland, R. (2016). What is the common data environment (CDE)? Retrieved from https://www.thenbs.com/knowledge/what-is-the-common-data-environment-cde

Meier, J. R., & Russell, J. S. (2000). Model process for implementing maintainability. *Journal of Construction Engineering and Management, 126*(6), 440-450. doi:10.1061/(asce)0733-9364(2000)126:6(440)

Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy, 97*, 355-364. doi:10.1016/j.apenergy.2011.11.075

Meng, X. (2013). Involvement of facilities management specialists in building design: United Kingdom experience. *Journal of Performance of Constructed Facilities, 27*(5), 500-507. doi:10.1061/(asce)cf.1943-5509.0000343

Meslec, M., & Ashworth, S. (2017). The value and influence of life cycle costing and assessment with BIM. *BIM Journal: BIM for FM, Clients, Owners and Operators, 5*, 60-61.

Micromain. (2017). What is facility management? Retrieved from https://www.micromain.com/what-is-facility-management/

Miller, D. C., & Salkind, N. J. (2002). Narrative research. In *Handbook of research design and social measurement*. Thousand Oaks, CA: Sage Publications.

Mills, E. (2011). Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions in the United States. *Energy Efficiency, 4*(2), 145-173. doi:10.1007/s12053-011-9116-8

Mirarchi, C., Pinti, L., Munir, M., Bonelli, S., Brizzolari, A., & Kiviniemi, A. (2018). Understand the value of knowledge management in a virtual asset management environment. In *Ework and ebusiness in architecture, engineering and construction* (pp. 13-20): CRC Press.

Moghtadernejad, S., Chouinard, L. E., & Mirza, M. S. (2018). Multi-criteria decision-making methods for preliminary design of sustainable facades. *Journal of Building Engineering, 19*, 181-190.

Mohammed, M. A., & Hassanain, M. A. (2010). Towards improvement in facilities operation and maintenance through feedback to the design team. *The Built & Human Environment Review, 3*, 72-87.

Moore, M., & Finch, E. (2004). Facilities management in South East Asia. *Facilities, 22*(9/10), 259-270. doi:10.1108/02632770410555986

Morgan, G., & Smircich, L. (1980). The case for qualitative research. *The Academy of Management Review, 5*(4), 491-500. doi:10.2307/257453

Mossman, A. (2013). Appendix C: Choosing by advantages. In J. Eynon (Ed.), *The design manager's handbook*: Wiley.

Munir, M., Kiviniemi, A., Finnegan, S., & Jones, S. W. (2019). BIM business value for asset owners through effective asset information management. *Facilities, 38*(3/4), 181-200. doi:10.1108/f-03-2019-0036

Nastasi, B. K., Hitchcock, J. H., & Brown, L. M. (2010). An inclusive framework for conceptualizing mixed methods design typologies: Moving toward fully integrated synergistic research models. *Handbook of Mixed Methods in Social & Behavioral Research, 2*, 305-338.

NBIMS-US. (2015). *National BIM standard - United States version 3*. Retrieved from https://www.nationalbimstandard.org/files/NBIMS-US_V3_3_Terms_and_Definitions.pdf

NCARB. (2019). NCARB by the numbers. Retrieved from https://www.ncarb.org/nbtn2019

Nelson, H. G., & Stolterman, E. (2003). *The design way: Intentional change in an unpredictable world: Foundations and fundamentals of design competence*. Englewood Cliffs, NJ: Educational Technology Publications.

Nielsen, A. N., Jensen, R. L., Larsen, T. S., & Nissen, S. B. (2016). Early stage decision support for sustainable building renovation–a review. *Building and Environment, 103*, 165-181.

Niknam, M., Jalaei, F., & Karshenas, S. (2019). Integrating BIM and product manufacturer data using the semantic web technologies. *Journal of Information Technology in Construction, 24*, 424-439.

Niknam, M., & Karshenas, S. (2017). A shared ontology approach to semantic representation of BIM data. *Automation in Construction, 80*, 22-36.

Nor, N. A. M., Mohammed, A. H., & Alias, B. (2014). Facility management history and evolution. *International Journal of Facilities Management, 5*(1).

Nourse, H. O. (1990). *Managerial real estate: Corporate real estate asset management*: Prentice Hall.

Nutt, B. (2000). Four competing futures for facility management. *Facilities, 18*(3/4), 124-132. doi:10.1108/02632770010315670

Oak, A. (2012). 'You can argue it two ways': The collaborative management of a design dilemma. *Design Studies, 33*(6), 630-648.

Oates, D., & Sullivan, K. T. (2011). Postoccupancy energy consumption survey of Arizona's LEED new construction population. *Journal of Construction Engineering and Management, 138*(6), 742-750.

Ogrodnik, K. (2019). Multi-criteria analysis of design solutions in architecture and engineering: Review of applications and a case study. *Buildings, 9*(12), 244.

Ornetzeder, M., Wicher, M., & Suschek-Berger, J. (2016). User satisfaction and well-being in energy efficient office buildings: Evidence from cutting-edge projects in Austria. *Energy and Buildings, 118*, 18-26. doi:10.1016/j.enbuild.2016.02.036

Oti, A. H., Kurul, E., Cheung, F., & Tah, J. H. M. (2016). A framework for the utilization of building management system data in building information models for building design and operation. *Automation in Construction, 72*, 195-210. doi:10.1016/j.autcon.2016.08.043

Oti, A. H., Tah, J. H. M., & Abanda, F. H. (2018). Integration of lessons learned knowledge in building information modeling. *Journal of Construction Engineering and Management, 144*(9), 4018081. doi:10.1061/(ASCE)CO.1943-7862.0001537

Papanek, V. (1985). *Design for the real world: Human ecology and social change / victor papanek* (2nd ed., completely rev ed.). London: Thames and Hudson.

Pärn, E. A., Edwards, D. J., & Sing, M. C. (2017). The building information modelling trajectory in facilities management: A review. *Automation in Construction, 75*, 45-55.

Parsons, G. (2015). *The philosophy of design*: Wiley.

Patton, M. Q. (2009). *Qualitative research & evaluation methods*. Thousand Oaks, CA: Sage Publications.

Phelps, A. F. (2012). *The collective potential: A holistic approach to managing information flow in collaborative design and construction environments*. United States: Turning Point Press.

Pikas, E., Koskela, L., & Seppänen, O. (2020). Improving building design processes and design management practices: A case study. *Sustainability, 12*(3), 911.

Pinsonneault, A., & Kraemer, K. (1993). Survey research methodology in management information systems: An assessment. *Journal of Management Information Systems, 10*(2), 75-105.

Plowright, P. D. (2014). *Revealing architectural design: Methods, frameworks and tools*. London: Routledge.

Poudelet, V., Chayer, J. A., Margni, M., Pellerin, R., & Samson, R. (2012). A process-based approach to operationalize life cycle assessment through the development of an eco-design decision-support system. *Journal of Cleaner Production, 33*, 192-201. doi:10.1016/j.jclepro.2012.04.005

Rainer, R. K., Prince, B., Splettstoesser-Hogeterp, I., Sanchez-Rodriguez, C., & Ebrahimi, S. (2020). *Introduction to information systems*: Wiley.

Ralph, P., & Wand, Y. (2009). A proposal for a formal definition of the design concept. In W. van der Aalst, J. Mylopoulos, N. M. Sadeh, M. J. Shaw, C. Szyperski, K. Lyytinen, P. Loucopoulos, & B. Robinson (Eds.), *Design requirements engineering: A ten-year perspective* (pp. 103-136). Berlin: Springer.

Rasmussen, H. L. (2020). The challenge of integrating operational knowledge in building and ship design. *Facilities, 39*(3/4), 136-155. doi:10.1108/f-10-2019-0106

Rasmussen, H. L., & Balslev, S. (2014). DTU says yes to operational friendly building but how should it be done in practice? *EuroFM Insight,* (31), 12-13.

Rasmussen, H. L., & Jensen, P. A. (2018). *Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings.* Paper presented at the Research Papers for the 17th EUROFM Research Symposium, Sofia.

Rasmussen, H. L., & Jensen, P. A. (2020). A facilities manager’s typology of performance gaps in new buildings. *Journal of Facilities Management, 18*(1), 71-87. doi:http://dx.doi.org/10.1108/JFM-06-2019-0024

Rasmussen, H. L., Jensen, P. A., & Gregg, J. S. (2017). *Transferring knowledge from building operation to design–a literature review.* Paper presented at the IRC 2017.

Rasmussen, H. L., Jensen, P. A., Nielsen, S. B., & Kristiansen, A. H. (2019). Initiatives to integrate operational knowledge in design: A building client perspective. *Facilities, 37*(11/12), 799-812. doi:10.1108/F-02-2017-0021

Reed, M. (2005). Reflections on the 'realist turn'in organization and management studies. *Journal of Management Studies, 42*(8), 1621-1644.

Remenyi, D. (1998). *Doing research in business and management: An introduction to process and method*. London: Sage Publications.

RICS. (2013). Strategic facilities management. In *RICS guidance note* (1st edition ed.). Coventry, UK: RICS.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155-169. doi:10.1007/bf01405730

Roberts, M., Allen, S., & Coley, D. (2020). Life cycle assessment in the building design process – a systematic literature review. *Building and Environment, 185*, 107274.

Robson, C. (2015). *Real world research* (4th ed.). New York: Wiley Textbooks.

Rowe, P. G. (1994). *Design thinking* (5th print ed.). Cambridge, MA: MIT Press.

Rowley, J. (2007). The wisdom hierarchy: Representations of the DIKW hierarchy. *Journal of Information Science, 33*(2), 163-180.

Ruikar, D., Anumba, C., Duke, A., Carrillo, P., & Bouchlaghem, N. (2007). Using the semantic web for project information management. *Facilities, 27*, 507-524.

Saaty, T. (1980). *The analytical hierarchy process*. New York: McGraw-Hill.

Saini, M., & Shlonsky, A. (2012). *Systematic synthesis of qualitative research*: OUP USA.

Sainter, P., Oldham, K., Larkin, A., Murton, A., & Brimble, R. (2000). *Product knowledge management within knowledge-based engineering systems.* Paper presented at the Design Engineering Technical Conference, Baltimore.

Sapp, D. (2017, 12/05/2017). Facilities operations and maintenance - an overview. Retrieved from https://www.wbdg.org/facilities-operations-maintenance

Saunders, M., Lewis, P., & Thornhill, A. (2015). *Research methods for business students* (7th ed.). New York: Pearson Education.

Schade, J., Olofsson, T., & Schreyer, M. (2011). Decision-making in a model-based design process. *Construction Management and Economics, 29*(4), 371-382. doi:10.1080/01446193.2011.552510

Scofield, J. H. (2013). Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings. *Energy and Buildings, 67*, 517-524.

Seeley, I. H. (1987). *Building maintenance*: Macmillan Education.

Serugga, J., Kagioglou, M., & Tzortzopolous, P. (2020). A utilitarian decision-making approach for front end design—a systematic literature review. *Buildings, 10*(2), 34.

Shen, W., Hao, Q., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., . . . Xue, H. (2010). Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review. *Advanced Engineering Informatics, 24*(2), 196-207.

Shiem-Shin Then, D. (1999). An integrated resource management view of facilities management. *Facilities, 17*(12/13), 462-469. doi:10.1108/02632779910293451

Siew, R. Y. (2015). Case study of an Australian residential college. *Journal of Facilities Management, 13*(4), 391-396.

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). Cambridge, MA: MIT Press.

Simpson, M. (2013). A definition of BIM. *The Structural Engineer, 91*, 6-9.

Sinclair, D. (2020). RIBA plan of work 2020 overview. In *RIBA*. London: RIBA.

Singhaputtangkul, N. (2017). A decision support tool to mitigate decision-making problems faced by a building design team. *Smart and Sustainable Built Environment, 6*(1), 2-18. doi:https://doi.org/10.1108/SASBE-06-2016-0009

Singhaputtangkul, N., & Low, S. P. (2015). Modeling a decision support tool for buildable and sustainable building envelope designs. *Buildings, 5*(2), 521-535.

Sloman, S., & Fernbach, P. (2018). *The knowledge illusion: Why we never think alone*: Penguin.

Smith, D. K. (2009). Building information modeling a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. In M. Tardif & I. Wiley (Eds.). Hoboken, NJ: Wiley.

Snyder, J. (1984). Introduction. In J. Snyder (Ed.), *Architectural research* (pp. 1-14). New York: Van Nostrand Reinhold.

Spence, E. H. (2011). Information, knowledge and wisdom: Groundwork for the normative evaluation of digital information and its relation to the good life. *Ethics and Information Technology, 13*(3), 261-275. doi:10.1007/s10676-011-9265-7

Standard, E. (2006). En15221-1: 2006. In *EN15221-1: 2006* (Vol. EN15221-1: 2006).

Stevenson, A. (2010). *Oxford dictionary of English*: Oxford University Press.

Stickdorn, M., Schneider, J., Andrews, K., & Lawrence, A. (2011). *This is service design thinking: Basics, tools, cases* (Vol. 1). Hoboken, NJ: Wiley.

Støre-Valen, M. (2021). FM and clinical employees' involvement in the design of eight Norwegian hospital projects. *Facilities, 39*(11/12), 778-801. doi:https://doi.org/10.1108/F-06-2020-0076

Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of Management Journal, 49*(4), 633-642. doi:https://doi.org/10.5465/AMJ.2006.22083020

Suhr, J. (1999). *The choosing by advantages decisionmaking system*. Westport, CT: Greenwood Publishing Group.

Sunnersjö, S. (2010). A taxonomy of engineering knowledge for design automation. *Tools and Methods of Competitive Engineering, 1-2*, 1339-1340.

Szykman, S., Fenves, S. J., Keirouz, W., & Shooter, S. B. (2001). A foundation for interoperability in next-generation product development systems. *Computer-Aided Design, 33*(7), 545-559. doi:10.1016/s0010-4485(01)00053-7

Tashakkori, A., & Teddlie, C. (2003). *Handbook of mixed methods in social & behavioral sciences*. Thousand Oaks, CA: Sage Publications.

Teicholz, E. (2001). *Facility design and management handbook*: McGraw Hill Professional.

Teicholz, P. M. (2013). *BIM for facility managers*. Hoboken, NJ: Wiley.

Temi. (2017). Temi: Privacy policy. Retrieved from https://www.temi.com/privacy

Thaler, R. H., & Sunstein, C. R. (2009). *Nudge: Improving decisions about health, wealth, and happiness*: Penguin.

Thorndike, E. L. (1913). *The psychology of learning: Educational psychology*. New York.

Tongco, M. D. C. (2007). Purposive sampling as a tool for informant selection. *Ethnobotany Research and Applications, 5*, 147-158.

Trochim, W. M. K. (2006, October 20). Web center for social research methods. *Nonprobability Sampling.* Retrieved from http://www.socialresearchmethods.net/kb/sampnon.php

Tucker, M., & Masuri, M. R. A. (2016). The rationale to integrate facilities management into the development process. *Property Management, 34*(4), 332-344. doi:10.1108/pm-08-2015-0040

Uniclass. (2020, Sept. 09). Uniclass 2015. *Uniclass 2015.* Retrieved from https://www.designingbuildings.co.uk/wiki/Uniclass_2015

Valiris, G., & Glykas, M. (1999). Critical review of existing BPR methodologies. *Business Process Management Journal, 5*(1), 65-86. doi:10.1108/14637159910249117

van Aken, J. E. (2005). Management research as a design science: Articulating the research products of mode 2 knowledge production in management. *British Journal of Management, 16*(1), 19-36. doi:10.1111/j.1467-8551.2005.00437.x

van der Meer, J., Hartmann, A., van der Horst, A., & Dewulf, G. (2019). Multi-criteria decision analysis and quality of design decisions in infrastructure tenders: A contractor's perspective. *Construction Management and Economics, 38*(2), 172-188. doi:10.1080/01446193.2019.1577559

Varcoe, B. (2000). Implications for facility management of the changing business climate. *Facilities, 18*(10/11/12), 383-391. doi:10.1108/02632770010349619

Velasquez, M., & Hester, P. T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research, 10*(2), 56-66.

Vianello, G., & Ahmed, S. (2009). *Knowledge transfer between service and design phases in the oil industry*. Paper presented at the DS 58-8: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Palo Alto, CA.

Von Krogh, G., Nonaka, I., & Aben, M. (2001). Making the most of your company's knowledge: A strategic framework. *Long Range Planning, 34*(4), 421-439.

Wang, H., & Meng, X. (2021). BIM-supported knowledge management: Potentials and expectations. *Journal of Management in Engineering, 37*(4), 04021032.

Wang, H., Meng, X., & McGetrick, P. J. (2018). Early contractor and facility management team involvement in the BIM environment. *Periodica Polytechnica Architecture, 49*(1), 47-58.

Wang, Y., Wang, X., Wang, J., Yung, P., & Jun, G. (2013). Engagement of facilities management in design stage through BIM: Framework and a case study. *Advances in Civil Engineering, 2013*, 1-8. doi:10.1155/2013/189105

Watson, R. T., & Webster, J. (2020). Analysing the past to prepare for the future: Writing a literature review a roadmap for release 2.0. *Journal of Decision Systems, 29*(3), 129-147.

Way, M., & Bordass, B. (2005). Making feedback and post-occupancy evaluation routine 2: Soft landings – involving design and building teams in improving performance. *Building Research & Information, 33*(4), 353-360. doi:10.1080/09613210500162008

WBDG. (2021, 04/09/2021). Building information modeling (BIM). *Whole Building Design Guide.* Retrieved from https://www.wbdg.org/bim

WBDG. (n.d.). NAVFAC building information management and modeling (BIM) & facility electronic operation and maintenance support information (EOMSI) program. Retrieved from https://www.wbdg.org/ffc/navy-navfac/bim-eomsi

Webber, L., & Wallace, M. (2011). *Quality control for dummies*: Wiley.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly*, xiii-xxiii.

Weeks, D. J., & Leite, F. (2021). Facility defect and cost reduction by incorporating maintainability knowledge transfer using maintenance management system data. *Journal of Performance of Constructed Facilities, 35*(2), 04021004.

Wohlin, C. (2014). *Guidelines for snowballing in systematic literature studies and a replication in software engineering*. Paper presented at the Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, New York.

Wong, K. K., Kumaraswamy, M., Mahesh, G., & Ling, F. Y. (2014). Building integrated project and asset management teams for sustainable built infrastructure development. *Journal of Facilities Management, 12*(3), 187-210. doi:https://doi.org/10.1108/JFM-05-2013-0025

Yang, Y. Q., Wang, S. Q., Dulaimi, M., & Low, S. P. (2003). A fuzzy quality function deployment system for buildable design decision-makings. *Automation in Construction, 12*(4), 381-393. doi:10.1016/s0926-5805(03)00002-5

Yin, R. K. (2017). *Case study research and applications: Design and methods*: Sage Publications.

Zerjav, V., Hartmann, T., & Achammer, C. (2013). Managing the process of interdisciplinary design: Identifying, enforcing, and anticipating decision-making frames. *Architectural Engineering and Design Management, 9*(2), 121-133.

Zhu, L., Shan, M., & Hwang, B.-G. (2018). Overview of design for maintainability in building and construction research. *Journal of Performance of Constructed Facilities, 32*(1), 04017116.

Zins, C. (2007). Conceptual approaches for defining data, information, and knowledge. *Journal of the American Society for Information Science and Technology, 58*(4), 479-493.

APPENDICES

Appendix A: IFMA Core Competencies

IFMA Core Competencies of Facility Management (IFMA, n.d.-a)
IFMA Definition of FM: *A profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology.*
1. Communication a. Manage and oversee the development and use of the facility communications plan. b. Prepare and deliver messages that achieve the intended results.
2. Emergency Preparedness and Business Continuity a. Plan, manage and support the entire organisations emergency preparedness program. b. Manage and oversee and support the entire organisation's business continuity program.
3. Environmental Stewardship and Sustainability a. Plan, manage and support the entire organisation's commitment to protecting the environment. b. Manage and oversee the entire organisation's commitment to sustainability of the natural and built environments.
4. Finance and Business a. Manage and oversee the financial management of the facility organisation. b. Administer and manage the finances associated with contracts c. Administer procurement and chargeback procedures.
5. Human Factors a. Develop and implement practices that support the performance and goals of the entire organisation. b. Develop and implement practices that support the performance of the facility organisation.
6. Leadership and Strategy a. Lead the facility organisation. b. Provide leadership to the entire organisation. c. The competent facility manager is able to plan strategically. d. Align the facility's strategic requirements with the entire organisation's requirements. e. Develop and implement a strategic planning process. f. Assess what services are needed to meet organisational (business) requirements.
7. Operations and Maintenance a. Assess the condition of the facility. b. Manage/oversee facility operations and maintenance activities. c. Manage/oversee occupant services (parking, janitorial services, food services, concierge, facility helpdesk, security, and safety). d. Manage/oversee the maintenance contracting process. e. Develop, recommend, and manage/oversee the facility's operational planning requirements (temperature control, lighting, equipment replacement, and so forth).
8. Project Management a. Plan projects b. Manage/oversee projects
9. Quality a. Develop and manage/oversee the creation and application of standards for the facility organisation. b. Measure the quality of services provided. c. Manage/oversee the improvement of work processes. d. Ensure and monitor compliance with codes, regulations, policies, and standards.
10. Real Estate and Property Management a. The competent facility manager is able to develop and implement the real estate master plan. b. The competent facility manager is able to manage/oversee real estate assets.
11. Technology a. Plan, direct and manage/oversee facility management business, and operational technologies.

Appendix B: Ethics Approval

Research, Innovation and Academic Engagement Ethical Approval Panel

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

T +44(0)161 295 5278

www.salford.ac.uk/

23 October 2018

Paul Long

Dear Paul,

RE: ETHICS APPLICATION STR1819-03: Improving architecture and engineering design decisions through the transfer of facility management and operations knowledge, information, and data to architecture and engineering design teams.

Based on the information you provided, I am pleased to inform you that your application STR1819-03 has been approved.

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

Yours sincerely,

APHigham.

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

Appendix C: Semi-Structured Interview Prompt

Prompt – Semi-Structured Interview

Background Information

1. Please briefly describe the company or institution for which you work and your current role(s)?

2. How long have you worked professionally? How long have you worked in your current position?

3. How aware are you of the facility management (or A/E) design profession?

4. How often do you work on design, construction, or refurbishment projects that have a facility manager?

   (or) As a facility manager, how often do you work on design, construction, or refurbishment projects?

5. Based on your professional experience, how would you describe the relationship between A/E design teams and facility managers?

Information/Data Tracking

6. Do any of the companies for which you have worked (or currently work) keep a database of 'lessons learned' from past projects?

   a. If so, what type of information/data do you track and how is the database kept?

7. Do any of the companies for which you have worked (or currently work) use a process for documenting key project decisions and/or requirement changes?

   a. If so, what was/is their process for documenting decisions or changes?

8. If you currently work in FM/O, or have worked, did/does the company or institution for which you work(ed) use any Performance Measurement Tools? (e.g., POE, Business Excellence Model, Balanced scorecard, KPI, Benchmarks)

   a. If so, which tools are/were used?

9. If you currently work in FM/O, what facility data or related information do you currently track (i.e., what benchmarks or KPIs)?

   a. How is this information tracked and stored?

   If you currently work in A/E, what data or related information would you like to receive from FM/O?

   b. How, and in what form, would you like to receive the data/information?

Relationships between FM/O and Design

10. What role, if any, do you think facility managers should have in A/E design processes?
11. Do you believe it would be helpful during the design process to provide design teams with historical operational data and information from existing facilities?
    a. Why or why not?
12. In your experience, based on past projects, how would you describe the availability of FM/O data to A/E design teams?
13. What FM/O data/info do you think would be valuable for design teams to be made aware?
    a. During what project phase do you think it would be most beneficial to provide this data?
14. What barriers do you think limit the consideration of existing FM/O data/info during design?
15. During which design phase(s) do you think it would be most beneficial for facility managers to be involved in design decision-making processes?
16. What do you think can be done to increase facility manager participation in design?
17. To what extent do you believe the digital exchange of data and information is sufficient to realise the benefits of FM inclusion in design (that person-to-person interaction is not necessary)?

BIM Related

18. How often do you utilise BIM authoring tools or related software on projects (Revit, ArchiCAD, Bentley Systems etc.)?
    a. Which do you use?
19. As a result of BIM, have you updated phase specific project requirements? (Such as project checklists, required deliverables, etc.)
    a. How, why, or why not?
20. If you currently work in FM/O, or have worked, did/does the company or institution for which you work maintain Asset Information Models (AIM), or equivalent?
    a. If so, how is the model maintained? / If not, why not?

Conclusion

Would you like to add anything to what we have discussed today?

Appendix D: Semi-Structured Interview Coded Excerpts

Semi-structured interview coded excerpts		
1. Unrealised benefit of FM involvement during the design process – 10/12 participants		
I-1 FM	14:32	I-1 FM (14:32): I've seen too many times where [I] go back through and see something that we probably could have picked out as being odd and something that could have been prevented or, you know, we have information that just a normal designer, or A/E firm wouldn't. I wish, they worked more together.
I-2 AE	1:21:26	I-2 AE (1:21:26): … there is no validation of our assumptions as designers. Now that client may have learned over the years that this works and this doesn't, so maybe that client has a little bit of a database but, at a design firm, you know, you have started, you make these assumptions and now you make it 15 more times that year alone because you've got that many projects. You know, like it's uh, I think, I think the FM has the ability to start to fill in those gaps.
I-3 AE	4:22 – 4:51	I-3 AE (4:22): There's a slight relationship, in some of, uh, on some of the projects we work on.
I-4 FMAE		I-4 FMAE (4:39): I would say that in my experience there is a poor communication between our architecture firm and the facility managers.
I-5 AE		I-5 AE (5:07): If there was a facility manager, then, I don't know, the communication [there would be a poor relationship?] Yes, if there was, yes.
I-6 FM	14:20 21:32 22:00 23:00	I-6 FM (14:20): …a lot of stuff you see it as it's coming in and as they're making it and you're thinking, why on earth did they do that? …I have some like VAV boxes that I have to do maintenance on that are eight feet above the ceiling and I can't even get to them. So, I'm going to have to get a lift and a ladder on top of the lift to even reach them. Where if I was involved early, you know, it's almost too late at some point to. I-6 FM (21:32): … there's certain things in this building that you'll see that, I'll say this is going to be a nightmare, but every single room has it. And for instance, like Barn Doors, we have sliding barn doors everywhere. Beautiful. I love them. They're really nice ones. They bought heavy duty ones. But if one kid slams that barn door, it's going to rip the hardware out of the ceiling. I already know what's going to happen. I-6 FM (22:00): …if somehow someone could keep track of how much money is spent on repairing things and if money would have been put in initially to just go with one standard, one step higher in quality that you would save money in the long run… I can walk you through this building and tell you what's going to work and what's not going to work. I-6 FM (23:00): …I have a lot of experience with meeting rooms and stuff. They don't, and I can tell you which ones are going to be used a lot. Which ones maybe they could have shared walls to make a bigger meeting room…
I-7 FMAE	NA	
I-8 FMAE	NA	
I-9 FM	35:12	I-9 FM (35:12) (speaking of the design and construction process): In my opinion, seasoned facility project managers make the best 'conductors' of this symphony.
I-10 AE	6:01, 6:36	I-10 AE (6:01) (speaking about the role of FM in design): … going beyond facility manager position down below like just like talking to people like the cleaning staff that are dealing with a building on a day-to-day basis… figuring out what could be more effective for them and where things aren't working out as they would like them to. (6:36) [There] should be a seat at the table. I feel like they should be reviewing designs and all of the key phases and giving us feedback on things we can do to improve.
I-11 FM	27:08	I-11 FM (27:08): yes, because the more information the better.
I-12 FMAE	20:35	I-12 FMAE (20:35): …we've been very successful and in fact we have been so successful that most of the projects that we've been executing the last year-and-a-half have been based on feedback that we've received from the operators, from facility managers because they see, they understand the building.
2. Lack of interdisciplinary awareness and respect limits FM involvement in design – 10/12 participants		
I-1 FM	18:01	I-1 FM (18:01): I don't think they realise… I know things are changing now with facility management, you know, being involved but I think that a lot of people that we work with are older firms and they're still kind of stuck in that rut of not consulting the FM… I think for some people it definitely is egos. …I've seen that with some of the oldest firms that we work with. I think the middle, we don't work with very many young, we don't work with very many old, but the middle, I think they just don't know. I know it wasn't really, I think it was around them, but it wasn't as well-known what FM is. There wasn't a real name, you know, facility management wasn't a name for it.
I-2 AE	34:47	I-2 AE (34:47): …most designers don't know anything about facility managers. So, they wouldn't necessarily know what to ask for.
I-3 AE	17:41	I-3 AE (17:41): In my experience it's very rare that I actually see a facility manager and talk with facility managers.
I-4 FMAE	NA	

I-5 AE	19:16	I-5 AE (19:16): …they're not included in any of the conversations. So, we don't even know. We don't even know if they have one.
I-6 FM	22:00	I-6 FM (22:00): ...but yeah, I can walk you through this building [in process of being built] and tell you what’s going to work and what’s not going to work.
I-7 FMAE	34:06	I-7 FMAE (34:06) ...I just think it would be nice for the engineers and architects to be aware of like, yeah, you design this thing.
I-8 FMAE	NA	
I-9 FM	54:01	I-9 FM (54:01): ...I’m not sure that practitioners [designers] really understand how people work [building users].
I-10 AE	7:24	I-10 AE (7:24): [Would you describe the availability of FM or operations data to design teams?] It’s non-existent.
I-11 FM	29:47	I-11 FM (29:47) (discussing whether FMs have information worth sharing with AE teams): I'm sure there is, but specifically, I don't know what would be, what would work best for them?
I-12 FMAE	19:03	I-12 FMAE (19:03): … often times the importance of facility management is overlooked and, and other very important item that needs to be taken into consideration is the fact that facility managers are often looked as inferior to architectural/engineering design teams because traditionally a facility manager doesn't have educational background in architectural engineering. As a result, …they're not able to often clearly articulate what the problem is even though the issue might be a valid concern.
3. Lack of decision-making processes and decision tracking limits knowledge sharing – 11/12 participants		
I-1 FM	8:29	I-1 FM (8:29): …we had a firm work on campus that ended up doing a horrible job after they were done with the work. We actually had to hire someone else to come in and fix their mistakes. And then we hired them again for another project and we were let down again. And so, we realized that they didn't do anything with the information we gave them.
I-2 AE	1:09:16	I-2 AE (1:09:16): I know on the design side that having something, physical to record design decisions would be very beneficial and produce less headaches for me.
I-3 AE		I-3 AE (9:08): I’m not aware [of any tracking system].
I-4 FMAE	9:08	I-4 FMAE (9:10): I’m unaware [of any tracking system].
I-5 AE		I-5 AE (9:14): um, no, not specifically [aware of any tracking system].
I-6 FM	8:21	I-6 FM (8:23): [does it document why the decision was made?] Absolutely not. It just updates it.
I-7 FMAE	7:45	I-7 FMAE (7:45) ...I think performance specs will be driven, like you’re designing a thing to operate in this way and if it doesn’t operate in this way, you’re financially liable...
I-8 FMAE	12:28	I-8 FMAE (12:28) ...we don’t go back and look at them a lot. Um, we’re forward progress. So, we’ll be aware of the mistake. Not necessarily the who, but the why. Um, I haven’t seen or been in, I’ve been part of several projects, I haven’t seen where we’ve made a discovery where it makes it back to that checklist.
I-9 FM	1:10:09	I-9 FM (1:10:09): [Is there value in me making a better decision?] No, no. Just decide.
I-10 AE	4:09	I-10 AE (4:09): The documents, major decisions, or changes? No, we barely get contracts in time...It’s non-existent.
I-11 FM	NA	
I-12 FMAE	54:30	I-12 FMAE (54:30): So perhaps that was not the best design decision for that specific, you know...Facilities needs to be able to give that feedback and say we don’t have confidence because we’ve seen B, C, and D, and then the designer can make, you know, an appropriate decision, which is specifically for that application. What’s gonna work well, what doesn’t work well? Yeah.
4. Poor knowledge management limits knowledge sharing – 11/12 participants		
I-1 FM	3:52 5:31	I-1 FM (3:52): …the construction manager keeps that sort of thing that you know, we can, we can meet with him and discuss and he'll kind of guide us towards what happened last time, but as one that we can access at any time, no. I-1 FM (5:31): …he's really good about keeping all of his little scribbles, all of his personal notes from when we go back in. And…sometimes he has physical ones. He'll, like you said, you'll pull those notes out of a filing drawer or he'll say, well, I don't have this anymore, but I can tell you from my experience last time.
I-2 AE	20:11	I-2 AE (20:11): … it's more of a mental thing. Like, oh, I use this because it did work one time or I don't like this brick because, you know, I used it on a project, and it was crap…
I-3 AE	5:48	I-3-AE (5:48): No, I think that's just by word of mouth.
I-4 FMAE	5:52	I-4 FMAE (5:52): We just every month "lessons learned for the month", and it's unhelpful. …no, and we have a meeting with our company and one guy says three lessons learned from the month that are extremely specific to the project and it's very unhelpful for the rest of firm.
I-5 AE	6:13	I-5 AE (6:13): Yes, and no. Um, for example, unrolling forms and dimensioning and exporting that to a spreadsheet and then you can reuse that information to fabricate or analyse the data.
I-6 FM	6:45	I-6 FM (6:45): It’s probably not available to the designers. It’s more like an operations standpoint.

I-7 FMAE	1:30:09	I-7 FMAE (1:30:09): If the tool that your work could produce would allow mistakes to be fed into a database that surmounts the confidentiality issues, um, liability issues, uh, but still made that information available easily to a new designer doing a new project, it would be an incredible tool.
I-8 FMAE	7:58 8:39	I-8 FMAE (7:58): …You have to know the project exists and you have to have rights and access to that… [Interviewer: But if you don't know another project exists, there's not an easy way for you to discover that?] I-8 FMAE (8:39): Right. And the projects are so broad. So, one of them, I mean it sounds stupid, but it is a barrier is like, so a lot of our projects, um, have some industry concerns for secrecy. So, they're named something totally unrelated to what the project is. Like, the recent projects are based on a Marvel character theme. So, a project grouped by, um, Marvel Cerebro, you know, and so if that terminology, it's used within the project team and if it gets out because we have lots of contractors working on it, nobody knows what it is. But that's also the problem. If you weren't involved in that project, it's hard to map that.
I-9 FM	NA	
I-10 AE	3:02	I-10 FM (3:02) (discussing tracking and sharing lessons learned): …lessons learned, like not specifically, you know, that's more just kept in the memory bank. … in terms of, of lessons learned, I mean, you know, those are just usually discussed at meetings.
I-11 FM	13:15	I-11 FM (13:15): We had a home system and uh, was really keen on documenting everything in there. And I mean it was almost like a detriment because in order to communicate with somebody, we would have to go through a help desk.
I-12 FMAE	1:00:41 1:20:46	I-12 FMAE (1:00:41): So generally speaking, record keeping I think is very poor in the facility management industry. Uh, they put like very little emphasis to it. And again, that's because I think, you know, people aren't attending to emergencies, reactive repairs. And the last thing somebody wants to do is keep good records of what has transpired. You know, the last year because they're running from one emergency to another. Unfortunately, you know, like, that doesn't provide enough information to educate better design decisions. …something that could be avoided is not avoided because the data perhaps is there or perhaps it's documented but not documented well enough. Or there's a lot of tacit knowledge that people, you know, like are not willing to pass along because typically tacit knowledge is equal to job security. They feel that if they're documented in such a way that everybody could do the job, they may run out of a job. (1:20:46) …Cause there's a lot of time being wasted hunting for information that you can't really find. And often times facilities would get frustrated and say the heck with that, you know, we don't have anything on it.
5. FM involvement should be focused early but ongoing – 11/12 participants		
I-1 FM	20:53	I-1 FM (20:53): I think a lot of it will be loaded in the front, but I think you don't want to overwhelm with information at the beginning because then they're just going to kind of dismiss it as, oh, they sent us a packet of information that we don't need. Um, I think it would need to be phased in a sense that as you're moving through, because I think a lot of what the issue is as facility managers when we're working with an A/E firm, you know, we'd give them what we've developed. They give us what they've developed and there's not a lot of us both being there at the same time kind of thing. Um, being involved through that whole process and being able to relay that information as we go…
I-2 AE	48:59	I-2 AE (48:59): Yeah, I would say starting at design development. Even some level in schematic design, but definitely design development, construction documents. (35:25) I think, at a minimum level, they should be reviewing drawings, at major milestones within the client. …and I think at a minimum level the facility manager should be involved in that process. Um, but, at the same time, I think it would be much more beneficial to have them at the table, doing all the design meetings, especially when it starts coming to uh, you know, like design development and you're starting to kind of figure out exactly where you're going when it comes to equipment or maybe not schematic design so much because that stuff's not, other than form, and kind of general direction.
I-3 AE		I-3 AE (16:08): I think the earlier you have the information the better you can prepare for.
I-4 FMAE	16:20	I-4 FMAE (16:40): I would say DD, uh, just because at the schematic phase you're still trying to really figure out what your idea is.
I-5 AE		I-5 AE (17:00): I would say DD.
I-6 FM	25:25	I-6 FM (25:25): I would think in the first half of the project, that's when all of that is, I mean, I don't think any decision should be made without looking at that data.
I-7 FMAE	0:10	I-7 FMAE (0:10) ... [and it should be in] that very early stage that you were talking about before, where you, you're trying to make decisions, but you don't have information.
I-8 FMAE	35:06	I-8 FMAE (35:06): So, I've never thought of it that way because we've never had that available. Um, I think certainly it has a place in, um, in early management.
I-9 FM	24:44	I-9 FM (24:44): It is important that the broad team have the appropriate engagement during the entire process.
I-10 AE	25:21	I-10 AE (25:21): I think you should have a major role at some point. I just don't know when that point would be…

		And probably the sooner the better because after the design is made and um, you know, calculations are completed, it, it might already be too late to, to change.
I-11 FM	NA	
I-12 FMAE	1:16:10	I-12 FMAE (1:16:10): We also like, it also helped us a lot, to shorten some of these timelines, and you know, make better decisions if you [get the information] like, at the front end.
6. Digital and face-to-face knowledge sharing is necessary – 11/12 participants		
I-1 FM	25:36	I-1 FM (25:36): I think it can be done digitally. I really do. …I do think there is a benefit to, um, being on a personal basis, but there's no reason that it couldn't be done digitally if it's done correctly.
I-2 AE	53:14	I-2 AE (53:14): I think a database, if it's maintained well and accurately will provide, I think the information it provides would be better and more inclusive than a person to person talks, because you won't necessarily remember why you made certain decisions back in design development that have maintained throughout the whole project. You will know why this changed to this during construction, so if you can turn to an all-inclusive location for information, again it is, the design team has to maintain it accurately. Um, but if that were done, I think that would be much more useful to those people managing the facility. Yeah. Then just a sit-down and chat kind of thing.
I-3 AE	22:47 24:43	I-3 AE (22:47): I think with them, with some interaction at the meetings you can kind of gauge like how passionate or maybe how important their feelings about certain issues because on paper two issues might look the same. But if the person is actually there you can kind of understand that one issue might be more important or that they are having more issues with one issue as opposed to another. So, I'll prioritize some stuff. (24:43) …another reason I think it's crucial is because if there is that intermediate stuff that you're hearing information from someone else, the FM can be there to either verify or deciding to get for that clarification.
I-4 FMAE	23:50	I-4 FMAE (23:50): Uh, so I definitely think the data itself is important because it's a way to, uh, as a documentation of how things are actually happening. Uh, but I also think it's important to be able to communicate with the person that is, uh, you know, managing the facility in terms of what they're frustrated with on a day-to-day basis or what the things they spend the most time on. Because then that can lead to other solutions that might not come out of just looking at a spreadsheet.
I-5 AE	24:19	I-5 AE (24:19): I think you need both of them simultaneously. Um, where that digital data, the spreadsheets, you may interpret stuff differently than is actually the case where the FM knows the day-to-day basis how things go, what the data actually comes down to and how like crucial that data is.
I-6 FM	30:24	I-6 FM (30:24): I think you have it [information and data]. You give it to them, you let them look at it and then I think that meeting has to be in place to explain what even they're looking at because unless they've dealt with that industry, I think they might not even realise what they're looking at. [Interviewer: So, you think you would need both?] I-6 FM (30:41): Definitely.
I-7 FMAE	NA	
I-8 FMAE	29:21	I-8 FM (29:21): …data's not the problem. You can drown in data. The problem is laser focus, grabbing, timing of when you need it and um, what's useful, you know.
I-9 FM	Written Notes	I-9 FM (Written Notes): Databases help incorporate existing operational functions into the design of a new building, but ownership comes from being involved in the decision process.
I-10 AE	9:25	I-10 AE (9:25) (speaking of digital vs face-to-face interaction): as a sole means of communication, I think it's inadequate. It's, there's so much information in the drawing set and in specs and everything, that stuff can very easily get lost. So, I think you really need that [personal] interaction and double checking together.
I-11 FM	39:09	I-11 FM (39:09): Yeah, you need to get together around the table, understand what's the need of the project or the design.
I-12 FMAE	1:08:45	I-12 FMAE (1:08:45): I think both is very, very important. …based on what I've seen, the facility management team has to deal with day-to-day operation, any as well as emergencies. Oftentimes, they don't have the time or perhaps they don't want to dedicate the time to sift through digital information or information that's provided to them in writing. I think a combination of both is very important. You exchange those ideas [digitally]. But you have that in person, perhaps like sit down where you walk them through [it] and perhaps… as you're getting more used to that model of exchanging information that day-to-day human interaction is reduced drastically. But I think at the beginning [having both] is very important, especially when you're trying to get a new technology accepted and understood.

Appendix E: Online Questionnaire

A/E-FM Knowledge Sharing in Design Decision-Making Processes

Survey Introduction

The following survey seeks opinions on the relationship between facility managers and design teams during the architecture/engineering (A/E) design process. The survey aims to investigate A/E and facility management (FM) knowledge sharing and integration within design decision-making processes. It additionally seeks to uncover opportunities and mechanisms to improve such integration, with the goal of improving A/E design decisions. In this regard, the survey has been developed to solicit views on how to improve FM-Design knowledge sharing and integration. This questionnaire consists of 28 research questions (17 background questions and 11 topical questions) and is designed to take approximately 10 - 15 minutes to complete. Your opinions are important in developing this work and are much appreciated.

Please answer the following questions to the best of your ability based on your professional experience and opinions. Questions which allow multiple answers are identified as such. You may also skip questions as you wish. All responses will be anonymous, but if you would like to see the results of the survey, or participate in future related research, you may include your email at the end of the questionnaire.

Thank you,

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A/E-FM Knowledge Sharing in Design Decision-Making Processes

Informed Consent for Participation in the Study

Please read the following and acknowledge your informed consent below before completing the following survey.

Project Title: Improving architecture and engineering design decisions through the transfer of facility management and operations knowledge, information, and data to architecture and engineering design teams.

Contact Information

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Project Details: You are invited to participate in an online survey investigating the integration of facility management (FM) expertise into architectural/engineering (AE) design processes. Researchers are interested in identifying the perceived benefits of integrating facility management and operations expertise in design, as well as investigating barriers limiting such integration. **We estimate it will take approximately 10 minutes to answer the survey questions.** You may refuse to answer any question at any time without consequence. If you do not wish to answer a question, you may skip any question(s) you choose or exit the survey at any time. However, please be aware that responses that have been made up to the point of exit will not be withdrawn – if you wish to 'erase' previous responses before exiting the survey, you will need to backtrack through the survey.

Benefits of Participation: Information collected will indirectly benefit facility management and architecture/engineering design professionals by helping identify opportunities for the disciplines to work more effectively together. The survey data will be collected anonymously, and the topic is not sensitive. The data will be used to inform academic publications. Participation or nonparticipation in this study will not impact your relationship with the University of Salford or researchers in any way.

Compensation: Compensation will not be provided for participation in this survey.

Risks: Participation in this survey presents no greater risk than what one encounters in daily life.

Confidentiality and Anonymity: Your contributions to the project will be treated with confidence and your data will be held and used on an anonymous basis. Your responses to this survey will not be used other than for the purposes described above and third parties will not be allowed access to them (except as required by the law). Your data will be held in accordance with relevant laws and regulations. You will not be personally identifiable in any of the output from this survey. The results of this study may be published in research articles but will not include any information that would identify you.

Further Questions or Complaints: If you have questions about this study, please contact the Principal Investigator listed above. If you have questions about your rights as a participant, would like to file a complaint, or if you would like to discuss with someone else at the University of Salford, please contact the School of the Built Environment Research Ethics Panel at S&T-ResearchEthics@salford.ac.uk, or at +44 0161 295 5278. You may also contact the research supervisor, Dr Paul Coates, regarding any additional questions at s.p.coates@salford.ac.uk, or at +44(0) 0161.295.2165.

* 1. **Participant's Statement of Informed Consent:**
Clicking on "**Agree**" below indicates you have read and understood the information about the project and that you voluntarily consent to participate in this research. Participation may be withdrawn at any time without giving a reason and without prejudice.

If you do not wish to participate in the research study, please decline participation by clicking on the "**Disagree**" button.

I voluntarily agree to participate and to the use of my data for the purposes specified above. I am aware that I can withdraw consent at any time by contacting the research team:

- ○ Agree
- ○ Disagree

A/E-FM Knowledge Sharing in Design Decision-Making Processes

Background Information

2. Which of the following most accurately describes your current title or position?

(If you fulfill multiple roles, please select all that apply)

- ☐ Architecture design team member (Including interior architecture/design)
- ☐ Engineering design team member
- ☐ Design consultant
- ☐ Facility management/operations team member
- ☐ Facility owner
- ☐ Facility management consultant
- ☐ Facility planner
- ☐ Academic (researcher or educator)
- ☐ Other (please specify)

3. How long have you worked professionally (over your whole career)?

- ◯ Less than one year
- ◯ 2 – 5 years
- ◯ 5 – 10 years
- ◯ 10 – 20 years
- ◯ More than 20 years

Other (please specify)

4. In which of the following geographic areas do you primarily work?

(Please select all that apply)

- ☐ United States of America (USA)
- ☐ United Kingdom (UK)
- ☐ Canada
- ☐ Australasia
- ☐ China
- ☐ Europe
- ☐ Middle East
- ☐ Scandinavia and Finland
- ☐ Other (please specify)

5. In which of the following industry sectors do you primarily work?

(Please select all that apply)

- [ ] Commercial
- [ ] Education
- [ ] Government
- [ ] Healthcare
- [ ] Higher education
- [ ] Hotel or hospitality
- [ ] Institutional (not otherwise listed)
- [ ] Military or defense
- [ ] Multifamily residential
- [ ] Not applicable
- [ ] Other (please specify)

6. Which of the following professional credentials do you currently hold?

(Please select all that apply)

- [ ] Licensed or chartered architect
- [ ] Licensed or chartered engineer
- [ ] Licensed or chartered construction manager or construction engineer
- [ ] Licensed or chartered planner
- [ ] Credentialed facility manager (CFM, BIFM, RICS, EuroFM, etc.)
- [ ] Not applicable
- [ ] Other (please specify)

7. How aware are you of the facility management profession?

- ○ Not at all aware
- ○ Slightly aware
- ○ Somewhat aware
- ○ Moderately aware
- ○ Very aware
- ○ Other (please specify)

8. How aware are you of the architecture/engineering design profession?

- Not at all aware
- Slightly aware
- Somewhat aware
- Moderately aware
- Very aware
- Other (please specify)

9. Have you been involved in a new-build construction project or major renovation/refurbishment **within the last five years?**

- Yes
- No - any involvement I have had in a new-build construction project or major renovation/refurbishment was more than five years ago.
- I have never been involved in a new build construction project or major renovation/refurbishment.

If you answered yes to this question, approximately how many related projects have you worked on in the past five years?

10. How often have you worked on design, construction, or refurbishment projects that include the involvement of a facility manager?

- Never (0% of the time)
- Rarely (less than 10% of the time)
- Occasionally (about 30% of the time)
- Sometimes (about 50% of the time)
- Frequently (about 70% of the time)
- Usually (about 90% of the time)
- Always (100% of the time)
- Unsure
- Not applicable
- Other (please specify)

11. If you currently work in a facility management related role or have worked in one, does/did the company or institution for which you work maintain Asset Information Models* (AIM), or equivalent, of your facilities?

- Yes
- No
- Unsure
- Not applicable

If you answered yes to this question, how is the model maintained?

If you answered no, please briefly explain why an AIM is not maintained.

(Please provide your answer below)

* *An Asset Information Model (AIM) is a model that compiles the data and information necessary to support asset management, that is, it provides all the data and information related to, or required for the operation of an asset. An AIM can provide graphical and non-graphical data and information as well as documents and metadata. It can relate to a single asset or to a portfolio of assets.*

12. Do any of the companies for which you have worked (or currently work for) utilize a formal design decision-making process such as Lean, Choosing by Advantages (CBA), Six Sigma, Target Value Design (TVD), Axiomatic Design, Instinct Driven Approach (IDA), etc.?

- Yes, on all projects
- Yes, on some, but not all projects
- No
- Not that I'm aware of
- Not applicable

If you answered yes, what design-decision making process(s) is/was utilized?

If you answered no, please briefly explain why a formal design decision-making process was/is not utilized.

13. If you answered yes to the previous question, how are/were design-decisions documented?

- [ ] Not applicable

(Please provide your answer below)

14. Do any of the companies for which you have worked (or currently work for) keep a database of ‘lessons learned’ from past projects?

- ◯ Yes, on all projects
- ◯ Yes, on some, but not all projects
- ◯ No
- ◯ Not that I’m aware of
- ◯ Not applicable

If you answered no, please briefly explain why a database of 'lessons learned' from past projects is not kept.

15. If you answered yes to the previous question, in what form was/is this database kept?

(Please select all that apply)

- ☐ Project notes
- ☐ Spreadsheets
- ☐ Generic database (Microsoft Access, etc.)
- ☐ Proprietary system
- ☐ CAFM or related software
- ☐ BIM related software
- ☐ Not applicable
- ☐ Other (please specify)

16. What do you think would be the ideal method for keeping a record of ‘lessons learned’ from past projects?

(Please select all that apply)

- ☐ Project notes
- ☐ Spreadsheets
- ☐ Generic database (Microsoft Access, etc.)
- ☐ Proprietary system
- ☐ CAFM or related software
- ☐ BIM related software
- ☐ Not applicable
- ☐ Other (please specify)

17. Do any of the companies or institutions for which you have worked (or currently work) use a process for documenting key project or design decisions and/or requirement changes?

- ◯ Yes
- ◯ No
- ◯ Not applicable

If you answered yes, what was/is their process for documenting such decisions or changes?

If you answered no, please briefly explain why a process for documenting such project decisions or changes is not utilized.

18. What do you think is the ideal method for documenting key project or design decisions and/or requirement changes?

(Please select all that apply)

- ☐ Project notes
- ☐ Spreadsheets
- ☐ Generic database (Microsoft Access, etc.)
- ☐ Proprietary system
- ☐ CAFM or related software
- ☐ BIM related software
- ☐ Not applicable
- ☐ Other (please specify)

A/E-FM Knowledge Sharing in Design Decision-Making Processes

Topical Data Questions

19. Prior research has suggested that the inclusion of facility managers during design phases leads to better-performing facilities.

Based on your professional experience, what facility management/operations related data or information do you believe would be **most helpful** to provide from FM to A/E design teams?

20. How useful would the following facility management/operations data categories be to A/E design teams during the design process?

(Please provide additional answers as needed)

	Extremely useful	Very useful	Somewhat useful	Not so useful	Not at all useful
Janitorial unit costs	○	○	○	○	○
Janitorial cleaning frequency	○	○	○	○	○
Maintenance unit costs - corrective	○	○	○	○	○
Maintenance unit costs - scheduled	○	○	○	○	○
Maintenance unit costs - exceptional	○	○	○	○	○
Occupancy and use (space utilization)	○	○	○	○	○
Operational unit costs	○	○	○	○	○
Facility or employee productivity	○	○	○	○	○
Staffing or employee labor unit costs	○	○	○	○	○
Employee or customer/user satisfaction	○	○	○	○	○
Utility or energy consumption and/or unit costs	○	○	○	○	○

Other (please specify)

21. Do you agree or disagree with the following statement:

The **digital** exchange of facility data and information would be**sufficient** to realize the potential benefits of facility management inclusion during design (that person-to-person interaction is not necessary)?

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- No opinion
- Other (please specify)

22. Do you agree or disagree with the following statement:

A/E design rationale provided to facility management and operation teams would be **beneficial** to the facility operation and maintenance process?

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- No opinion
- Other (please specify)

23. Do you agree or disagree with the following statement:

Awareness of the rationale behind facility design decisions is **necessary** to effectively evaluate a facility's performance and design quality.

- ○ Strongly agree
- ○ Agree
- ○ Neither agree or disagree
- ○ Disagree
- ○ Strongly disagree
- ○ No opinion
- ○ Other (please specify)

24. During which project stages would it be most useful to transmit data and information **FROM** facility management/operations **TO** architecture/engineering design teams?

(Please select all that apply)

- ☐ Project definition – determining project feasibility
- ☐ Project planning/programming (PD)
- ☐ Schematic design (SD)
- ☐ Design development (DD)
- ☐ Construction documentation (CD)
- ☐ Construction administration (CA)
- ☐ Project closeout and warranty
- ☐ Project commissioning
- ☐ I do not think there is a need to involve facility management in design during any project stage
- ☐ No opinion
- ☐ Other (please specify)

25. During which project stages would it be most useful to transmit data and information**TO** facility management/operations **FROM** architecture/engineering design teams?

(Please select all that apply)

- ☐ Project definition – determining project feasibility
- ☐ Project planning (PD)
- ☐ Schematic design (SD)
- ☐ Design development (DD)
- ☐ Construction documentation (CD)
- ☐ Construction administration (CA)
- ☐ Project closeout and warranty
- ☐ Project commissioning
- ☐ I do not think there is a need to involve facility management in design during any project stage
- ☐ No opinion
- ☐ Other (please specify)

26. How familiar are you with the following building systems classification systems?

(Please select all that apply)

	Not at all familiar	Slightly familiar	Somewhat familiar	Moderately familiar	Very familiar
OmniClass (OCCS)	○	○	○	○	○
MasterFormat	○	○	○	○	○
UniFormat	○	○	○	○	○
Uniclass	○	○	○	○	○
IFC (Industry Foundation Classes)	○	○	○	○	○
COBie (Construction-Operations Building Information Exchange)	○	○	○	○	○
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	○	○	○	○	○
CAWS (Common Arrangement of Work Sections)	○	○	○	○	○
NRM (New Rules of Measurement)	○	○	○	○	○

Other (please specify)

27. Which of the following building systems classification systems do you regularly use (or have regularly used)?

(Please select all that apply)

	Never (0% of the time)	**Rarely** (less than 10% of the time)	**Occasionally** (about 30% of the time)	**Sometimes** (about 50% of the time)	**Frequently** (about 70% of the time)	**Usually** (about 90% of the time)	**Always** (100% of the time)	**I do not know**	**Not applicable**
OmniClass (OCCS)	◯	◯	◯	◯	◯	◯	◯	◯	◯
MasterFormat	◯	◯	◯	◯	◯	◯	◯	◯	◯
UniFormat	◯	◯	◯	◯	◯	◯	◯	◯	◯
Uniclass	◯	◯	◯	◯	◯	◯	◯	◯	◯
IFC (Industry Foundation Classes)	◯	◯	◯	◯	◯	◯	◯	◯	◯
COBie (Construction Operations Building Information Exchange)	◯	◯	◯	◯	◯	◯	◯	◯	◯
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	◯	◯	◯	◯	◯	◯	◯	◯	◯
CAWS (Common Arrangement of Work Sections)	◯	◯	◯	◯	◯	◯	◯	◯	◯
NRM (New Rules of Measurement)	◯	◯	◯	◯	◯	◯	◯	◯	◯
a Proprietary system	◯	◯	◯	◯	◯	◯	◯	◯	◯

Other (please specify)

28. To what extent do you think each of the following represents an **effective method** for transmitting data and information **between** facility management/operations and architecture/engineering design teams?

(Please select all that apply)

	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective	No opinion	Not applicable
OmniClass (OCCS)	○	○	○	○	○	○	○
MasterFormat	○	○	○	○	○	○	○
UniFormat	○	○	○	○	○	○	○
Uniclass	○	○	○	○	○	○	○
IFC (Industry Foundation Classes)	○	○	○	○	○	○	○
COBie (Construction-Operations Building Information Exchange)	○	○	○	○	○	○	○
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	○	○	○	○	○	○	○
CAWS (Common Arrangement of Work Sections)	○	○	○	○	○	○	○
NRM (New Rules of Measurement)	○	○	○	○	○	○	○
a Proprietary system	○	○	○	○	○	○	○

Other (please specify)

29. Which of the following mechanisms do you think would **encourage** the transfer of data and information between facility management/operations and architecture/engineering design teams?

(Please select all that apply)

- ☐ Building Performance Evaluations (PBE)
- ☐ Facility commissioning
- ☐ Including facility managers during project program development
- ☐ Including facility managers in design and construction phase project meetings
- ☐ Including facility managers in the writing of performance specifications
- ☐ Post Occupancy Evaluations (POE)
- ☐ Providing a mechanism for the easy transfer of digital data or information between FM and A/E design teams
- ☐ Requiring BIM deliverables to be handed over to facility managers or owners
- ☐ Requiring COBie submittals to be handed over to facility manager or owner
- ☐ Requiring IFC submittals to be handed over to facility managers or owners
- ☐ Soft Landings or other project data exchange requirements (ex. Operations and Maintenance Support Information (OMSI))
- ☐ I do not think there is a need to increase the transfer of data and information between facility management/operations and architecture/engineering design teams?
- ☐ No opinion
- ☐ Other (please specify)

30. Do you have any other thoughts related to the involvement of facility management in the architecture/engineering design process that you would like to share?

A/E-FM Knowledge Sharing in Design Decision-Making Processes

Survey Conclusion

If you would like to see the results of this study or be updated about its findings and future related work that seeks to develop tools to improve AE-FM knowledge sharing and integration, please click on the following link to be led to an anonymous email entry page. Your email will be kept separately and will remain anonymous from your answers submitted in this survey.

Anonymous Email Entry

Thank you for your time and for your willingness to complete this survey. Your opinions and answers to these questions are much appreciated and will be helpful in completing this research.

Please feel free to share this survey with any whom you feel may be interested or willing to complete the questionnaire.

Thank you,

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Appendix F: Online Questionnaire Raw Data

Q1: Respondent consent

Question 1		
Participant's Statement of Informed Consent: Clicking on "Agree" below indicates you have read and understood the information about the project and that you voluntarily consent to participate in this research. Participation may be withdrawn at any time without giving a reason and without prejudice. If you do not wish to participate in the research study, please decline participation by clicking on the "Disagree" button. I voluntarily agree to participate and to the use of my data for the purposes specified above. I am aware that I can withdraw consent at any time by contacting the research team:		
Answer Choices	**Responses**	
Agree	99.31%	143
Disagree	0.69%	1
	Answered	**144**
	Skipped	**0**

Q2: Respondent background

Question 2		
Which of the following most accurately describes your current title or position? (If you fulfil multiple roles, please select all that apply)		
Answer Choices	Responses	
Architecture design team member (Including interior architecture/design)	40.16%	51
Engineering design team member	3.15%	4
Design consultant	7.87%	10
Facility management/operations team member	42.52%	54
Facility owner	4.72%	6
Facility management consultant	5.51%	7
Facility planner	4.72%	6
Academic (researcher or educator)	9.45%	12
Other (please specify)	22.83%	29
	Answered	**127**
	Skipped	**17**

1. *Project Manager*
2. *Project Manager - Construction and Renovation Projects for Ferris State University*
3. *Retired. Facility management, major capital project design and construction manager, LEED consultant and trainer,*
4. *Design Director*
5. *Retired architecture professor and owner of an architectural firm.*
6. *Trade Contractor Operations Manager (former Architectural Technician)*
7. *Automotive Buyer/Project Manager. (Was a FM for 4 years before)*
8. *Government Oversight Authority*
9. *Asset manager, program assistant*
10. *State Funding Agency*
11. *Manager, customer success team Azolla - Acacia facilities management , Ireland*
12. *General know-it-all*
13. *US Army Corps of Engineers.*
14. *Construction Assistant Project Manager*
15. *Construction Project Estimator/Manager*
16. *Urban planner*
17. *BIM Manager*
18. *Urban Planner*
19. *Estimating, Project Management, Purchasing*
20. *Project Manager*
21. *Project Manager - Architectural Metals*
22. *Reality Capture Modeler*
23. *Sales/engineering*
24. *Construction Manager - Estimator*
25. *Construction Manager, General Contractor*
26. *Telecommunications Installation*
27. *Project Manager*
28. *home maker*
29. *Facilities user*

Q3: Years of professional experience

Question 3		
How long have you worked professionally (over your whole career)?		
Answer Choices	**Responses**	
Less than one year	3.15%	4
2 – 5 years	24.41%	31
5 – 10 years	19.69%	25
10 – 20 years	22.05%	28
More than 20 years	30.71%	39
Other (please specify)	3.15%	0
	Answered	**127**
	Skipped	**17**

Q4: Respondent geographic work location

Question 4		
Survey Respondent Geographic Areas of Work		
Answer Choices	**Responses**	
United States	93.70%	119
United Kingdom	3.94%	5
Canada	0.79%	1
Australasia	0.00%	0
China	0.79%	1
Europe	2.36%	3
Middle East	3.15%	4
Scandinavia and Finland	0.00%	0
Other (Worldwide)	2.36%	3
Note: Totals add up to more than 100% because respondents could select more than one answer - they could select "all that apply."		

Q5: Respondent industry work sector

Question 5		
In which of the following industry sectors do you primarily work? (Please select all that apply**)**		
Answer Choices	**Responses**	
Commercial	44.88%	57
Education	40.16%	51
Government	26.77%	34
Healthcare	14.17%	18
Higher education	24.41%	31
Hotel or hospitality	9.45%	12
Institutional (not otherwise listed)	9.45%	12
Military or defence	5.51%	7
Multifamily residential	8.66%	11
Not applicable	1.57%	2
Other (please specify)	16.54%	21
1. *Manufacturing* 2. *Single family residential, non-profit, real estate development* 3. *Most of our clients are blue chip multinational software companies* 4. *Culture - museums & exhibitions* 5. *rail - retail - residential - Government estates - blue chip banks* 6. *affordable housing development* 7. *Municipal* 8. *Architectural Historic Preservation* 9. *Single Family Residential* 10. *Single Family Residential* 11. *single family residential* 12. *Country Club* 13. *Pharmaceutical*	**Answered** **Skipped**	**127** **17**

14. *Energy Industry* 15. *Residential* 16. *Research* 17. *Residential & Light Commercial* 18. *RESIDENTIAL* 19. *Industrial* 20. *Laboratory* 21. *kitchen*	

Q6: Respondent professional credentials

Question 6		
Which of the following professional credentials do you currently hold? (Please select all that apply)		
Answer Choices	**Responses**	
Licensed or chartered architect	14.17%	17
Licensed or chartered engineer	5.83%	7
Licensed or chartered construction manager or construction engineer	5.00%	6
Licensed or chartered planner	0.83%	1
Credentialed facility manager (CFM, BIFM, RICS, EuroFM, etc.)	15.83%	19
Not applicable	50.83%	61
Other (please specify)	17.50%	21
1. *FMP-Facility Management Professional* 2. *MSCTE - Master of Science in Career and Technical Education* 3. *Formerly PE, LEED-AP* 4. *NCIDQ* 5. *Licensed real estate salesperson* 6. *Licensed mechanical contractor* 7. *none* 8. *Master Plumber, Gasfitter, Oil Burner Technician* 9. *Professor, and Department Chair* 10. *Certified Facilities Manager and Certified Facilities Engineer* 11. *Bachelor of Science and master's in public administration* 12. *Licensed construction manager, licensed electrician* 13. *Licensed Plumber, Licensed Construction Supervisor (Builder) Commonwealth of Massachusetts* 14. *Licensed or chartered interior designer* 15. *Certified Administrator of Public Parking (CAPP)* 16. *License builder* 17. *CM-BIM, LEED AP* 18. *CM-BIM; LEED AP BC+C* 19. *Allied ASID, IDEC, NEWH* 20. *BA* 21. *chartered technologist*	**Answered** **Skipped**	**120** **24**

Q7 – Q8: Awareness of AE-design and FM professions

Question 7		
How aware are you of the facility management profession?		
Answer Choices	**Responses**	
Not at all aware	2.36%	3
Slightly aware	6.30%	8
Somewhat aware	7.87%	10
Moderately aware	21.26%	27
Very aware	61.42%	78
Other (please specify)	0.79%	1
1. *Current President Elect of the Massachusetts Facilities Administrators Association*	**Answered** **Skipped**	**127** **17**

Question 8		
How aware are you of the architecture/engineering design profession?		
Answer Choices	Responses	
Not at all aware	0.00%	0
Slightly aware	1.63%	2
Somewhat aware	6.50%	8
Moderately aware	9.76%	12
Very aware	82.11%	101
Other (please specify)	0.00%	0
	Answered	123
	Skipped	21

Q9: Respondent new-build or major renovation involvement

Question 9		
Have you been involved in a new-build construction project or major renovation/refurbishment within the last five years?		
Answer Choices	Responses	
Yes	86.61%	110
No - any involvement I have had in a new-build construction project or major renovation/refurbishment was more than five years ago.	10.24%	13
I have never been involved in a new build construction project or major renovation/refurbishment.	3.15%	4
If you answered yes to this question, approximately how many related projects have you worked on in the past five years?		41
1. *20 to 30* 2. *40* 3. *Dozens* 4. *Over 10 major renovation projects exceeding $30M in construction costs. One new build construction project over $1.5B in construction costs.* 5. *5* 6. *1* 7. *~25* 8. *2* 9. *20-30* 10. *3* 11. *1* 12. *2* 13. *3* 14. *25+ new-build construction projects.* 15. *4* 16. *5* 17. *15* 18. *6* 19. *5* 20. *17* 21. *5* 22. *4* 23. *15-20 projects* 24. *1* 25. *2* 26. *Multiple* 27. *2* 28. *15* 29. *30+* 30. *7-Jun* 31. *6* 32. *50* 33. *2* 34. *1* 35. *4* 36. *ballpark around 20* 37. *20* 38. *4* 39. *3* 40. *2*	Answered Skipped	127 172

Q10 Construction project involvement of Facility Managers

Question 10		
How often have you worked on design, construction, or refurbishment projects that include the involvement of a facility manager?		
Answer Choices	Responses	
Never (0% of the time)	7.94%	10
Rarely (less than 10% of the time)	18.25%	23
Occasionally (about 30% of the time)	15.08%	19
Sometimes (about 50% of the time)	11.11%	14
Frequently (about 70% of the time)	16.67%	21
Usually (about 90% of the time)	7.14%	9
Always (100% of the time)	13.49%	17
Unsure	4.76%	6
Not applicable	2.38%	3
Other (please specify)	3.17%	4
1. *I am the facility manager, everything I do involves myself as a facility manager* 2. *As the project manager at the University, we ultimately are the facility manager.* 3. *As developer/owner/operator, we are all at the table* 4. *Grant program encourages facility manager involvement, limited direct interaction.*	**Answered** **Skipped**	**126** **18**

Q11: - Asset Information Models (AIM)

Question 11		
If you currently work in a facility management related role or have worked in one, does/did the company or institution for which you work maintain Asset Information Models* (AIM), or equivalent, of your facilities?		
Answer Choices	Responses	
Yes	24.19%	30
No	19.35%	24
Unsure	12.90%	16
Not applicable	43.55%	54
If you answered yes to this question, how is the model maintained? If you answered no, please briefly explain why an AIM is not maintained. (Please provide your answer below)		33
	Answered	**124**
	Skipped	**20**

Q12 and Q13: Design decision-making process

Question 12		
Do any of the companies for which you have worked (or currently work for) utilize a formal design decision-making process such as Lean, Choosing by Advantages (CBA), Six Sigma, Target Value Design (TVD), Axiomatic Design, Instinct Driven Approach (IDA), etc.?		
Answer Choices	Responses	
Yes, on all projects	5.60%	7
Yes, on some, but not all projects	16.00%	20
No	22.40%	28
Not that I'm aware of	47.20%	59
Not applicable	8.80%	11
If you answered yes, what design decision-making process(s) is/was utilised? If you answered no, please briefly explain why a formal design decision-making process was/is not utilized.		22
	Answered	**125**
	Skipped	**19**

Question 13		
If you answered yes to the previous question, how are/were design decisions documented?		
Answer Choices	**Responses**	
Not applicable	100.00%	68
(Please provide your answer below)		22
	Answered	**68**
	Skipped	**76**

Question 13 Comments

Documentation process used	Documentation process not used
By virtue of the pre-agreed milestones initiating client sign off (approval) - any changes post milestones would be subject to the pre-agreed change process & approval would be required ahead of implementation.	*It is not something I have personally engaged with, so, it is hard for me to say.*
Decision log tracking the initial request, decision maker/requester, decision reached/proposed, implementation status, and follow-up investigating whether it was successful.	*Again, not used with or by our design firms.*
Written documentation of process and decisions reached.	*Cannot answer to this regard because the projects were completed before I started at the present firm.*
They were first prioritized by need within the campus / building. Design decisions were made by incorporating the needs of the effected people, Facility Manager (me), and marrying that with the corporate-approved design ascetic.	
Design decisions were documents in meeting minutes taken by the Architect.	
Lean, Integrated Design Delivery, Design Assist.	
Via meeting notes or meeting minutes and scheduling tools like ASTA Powerproject	
Microsoft One Note	
Close and frequent coordination between me as the owner's representative and the project architect and lead engineers. Agendas, meetings, minutes, and needed follow up correspondence. Face-to-face whenever possible during programming and schematic design.	
Meeting minutes, sketching design with clients.	
Written reports and related documents.	
Written reports after CBA work sessions.	

Q14 – Q15: Database of lessons learned from past projects

Question 14		
Do any of the companies for which you have worked (or currently work for) keep a database of 'lessons learned' from past projects?		
Answer Choices	**Responses**	
Yes, on all projects	16.39%	20
Yes, on some, but not all projects	35.25%	43
No	25.41%	31
Not that I'm aware of	21.31%	26
Not applicable	1.64%	2
If you answered no, please briefly explain why a database of 'lessons learned' from past projects is not kept.		25
	Answered	**122**
	Skipped	**22**

1. *No but we try to update our design standards documents for future projects if we experience an issue on a previous project to hopefully avoid it in the future.*
2. *We don't use a database but do have Constructions Standards documents that outline our preferences and specify what will and will not be approved by the University. This includes building design, CSI spec info and product information.*
3. *The major component of "lessons learned" was maintained by long-term retention of the facilities project managers; when I left this role in the late 1990s, we had introduced many CAD functions, but computer operating systems were generally too slow to incorporate into the actual project implementation flow.*
4. *no time to administer*
5. *Lessons learned were typically discussed in meetings, not logged into a database.*
6. *Yes, they say they learned but never actually change*
7. *Cost prohibitive to develop a database system, as the majority of construction projects were smaller in scale (Lifecycle system replacement).*
8. *I don't know.*
9. *I have never heard of doing this, I just keep a mental note of 'lessons learned'.*
10. *I think on a personal level you keep the lessons learned so you don't repeat them, but as a company no this is not a practice that we use right now. May talk about them, but not documented.*

11. *Lack of capacity to do it. It's always an intention but we move so quickly and on to the next project with little capacity.* 12. *Unknown why it is not addressed and kept. It would be highly valuable to do so.* 13. *Lessons learned was treated more informally. There was no actual database other than our collective memories.* 14. *It has recently been talked about starting something like this - I am not sure why they don't I assume because it takes time.* 15. *Lack of resources and systems. Our organisation is behind on good systems for tracking results.* 16. *We don't make time to do it.* 17. *We have a round table series at lunch where we meet and discuss lessons learned from specific projects during different phases* 18. *It is hard to maintain and keep up with.* 19. *It' s really what each designer is aware of and keeps an eye out.* 20. *To clarify (and this question made me chuckle), yes, good projects and good lessons are typically put into the system. However, poor lessons and bad contractor experiences are typically stored in the mind (owner perspective/experience).* 21. *Small company with no formal process. Individuals had experience of lessons learned but no documentation.* 22. *Standards handbook was created and updated for details that are used at the firm* 23. *The database is not well maintained.* 24. *A formal database is not kept, rather it is in the heads of those who work there. Each project manager/principal has lessons learned that they pass along as it applies to their projects.* 25. *The amount of input required by AiM makes it undesirable to use to many employees. The amount of time that must be spent filling out reports outweighs any advantage the software might provide. Many personnel do not feel comfortable working in AiM as it is very easy to disturb work done by others on it.*	

Question 15		
If you answered yes to the previous question, in what form was/is this database kept? (Please select all that apply)		
Answer Choices	**Responses**	
Project notes	53.92%	55
Spreadsheets	32.35%	33
Generic database (Microsoft Access, etc.)	17.65%	18
Proprietary system	3.92%	4
CAFM or related software	4.90%	5
BIM related software	8.82%	9
Not applicable	34.31%	35
Other (please specify)	9.80%	10
1. *Cross team project meetings to share lessons learned and associated presentation material.* 2. *Point of Clarity - Again, I work for smaller groups/companies typically, so the President of the company keep all notes of any problems from past projects, but no formally documented/catalogued database. Typically, just a file folder with handwritten notes clasped in alongside a myriad of other project related notes.* 3. *Unknown* 4. *Verbal* 5. *This is a Microsoft word document with PDF attachments.* 6. *internal internet/database* 7. *Handbook* 8. *Written as comments into in-house specification files.* 9. *Notes written into spec documents and a running list in a Word document shared on office server.* 10. *A crm systems*	**Answered** **Skipped**	**102** 42

Q16: Ideal method for keeping lessons learned from past projects

Question 16		
What do you think would be the ideal method for keeping a record of 'lessons learned' from past projects? (Please select all that apply)		
Answer Choices	**Responses**	
Project notes	50.83%	61
Spreadsheets	41.67%	50
Generic database (Microsoft Access, etc.)	43.33%	52
Proprietary system	10.83%	13
CAFM or related software	17.50%	21
BIM related software	33.33%	40
Not applicable	2.50%	3
Other (please specify)	13.33%	16

1. *Our standards are a live document and get updated as issues happen in real time.* 2. *Depends on the tools and systems used in the organisation.* 3. *crm system or related multi access db* 4. *Spec related software* 5. *I do not know enough to recommend a good way to do it besides project notes* 6. *Project minutes & drawing set comments* 7. *I work in public K-12 arena and our industry would benefit from an archive that other projects could review as to avoid similar mistakes* 8. *an easily referenced and frequently updated checklist, ongoing changes to template drawings and details* 9. *Any formal database requires someone to review the information and then decide if a particular lesson might apply to a new and unique project. Seems unlikely to be effective.* 10. *Office wide presentation* 11. *Realistically, with our we are organisationally setup, it's difficult for us on the owner side to manage this formally. We lean more on our design and construction partners to update and revisit lessons learned as we move into new projects (via notes and meeting kick-off meetings).* 12. *unsure* 13. *Some sort of searchable data base. I am not a fan of home-grown solutions as they are difficult to maintain over the long term.* 14. *Perhaps somewhat more of an interactive meeting / presentation to go over and explain with questions and answers.* 15. *Whatever system is easy to use and navigate. I've been involved in several new software rollouts that no one really adopted.* 16. *data warehouse*	**Answered**	120	
	Skipped	24	

Q17 – Q18: Documenting key decisions and requirement changes

Question 17		
Do any of the companies or institutions for which you have worked (or currently work) use a process for documenting key project or design decisions and/or requirement changes?		
Answer Choices	**Responses**	
Yes	54.76%	69
No	27.78%	35
Not Applicable	17.46%	22
If you answered yes, what was/is their process for documenting such decisions or changes? If you answered no, please briefly explain why a process for documenting such project decisions or changes is not utilized.		62
1. *Documentation occurs in email form or in meeting minutes.* 2. *This is currently captured via meeting minutes and drawing mark-ups.* 3. *What - When - Who, in that order, so all management participants know the decision process prior to the start of construction. It often was done using 5" x 8" programming cards organized on a 20-foot long tackable wall. It provided the sequence of decision making and allowed the project team to determine when to ask for approvals (and funds), and reduced unanticipated snafus because we had some control over who made the decisions.* 4. *Notes in project file.* 5. *Change order Logs, spreadsheets, formalized lessons learned process, and reports generated by maintenance management software.* 6. *We develop an Owners Project Requirements document and then a Basis of Design document.* 7. *Through change orders and/or email, depending on the project, and cost implications.* 8. *Cost prohibitive to develop an IT system, as the majority of construction projects were smaller in scale (Lifecycle system replacement).* 9. *Projnet, Access, Word Doc's, Excel.* 10. *USACE rules apply...army has a very documented process with both civilian and mil projects* 11. *For large/complex projects a Basis of Design document would be utilized to document major design decisions. However, often times the BOD document would not be updated, as the A/E team was under extreme pressure to deliver the construction documents within shorter timeframes.* 12. *Meeting minutes or issues log / VE log spreadsheets.* 13. *e-builder* 14. *We do not do very many projects and if we do, they are small in scale.* 15. *Yes, all changes are documented on Procore.* 16. *We use Hubspot and Procore* 17. *Meeting minutes & drawing sets* 18. *"By virtue of the pre-agreed milestones initiating client sign off (approval) - any changes post milestones would be subject to the pre-agreed change process & approval would be required ahead of implementation* 19. *All decisions & changes would be recorded - the process would be pre-agreed & recorded for access by all comers within the PEP - the Project Execution Plan"* 20. *Meeting minutes* 21. *Internally created forms.*	**Answered**	**126**
	Skipped	**18**

22. *"In various ways: the digital tools and mobility lab frameworks I had been part of are part of the design process labs and majority of the research and documentation go into periodic publications.*
23. *We have also established manuals and guidelines for systems-based, analytic design approaches to urban planning through a product called PlanMetrics."*
24. *Email, Letters, other "written" forms of communication*
25. *We really should be doing this; however, we are very busy and the least we do is have the client either approve the change through email and saving that email in project folders. This is not a good process we should have a change order completed and signed by the client.*
26. *Information from job meetings, project notes and discussions with architects, engineers, and Owner Project Manager/Clerk of Works.*
27. *Spreadsheets*
28. *We don't have a formal process. Most Project Managers have a design, finance or law background so know when to elevate decision making (mostly around financial and cost related matters). That said, nothing is formally documented other than confirmation via email.*
29. *Building Committee votes and change orders handle changes in the field*
30. *Construction meeting notes that were transferred to spreadsheet and MS Word application.*
31. *Building committees meeting minutes*
32. *Meeting minutes reviewed and approved by the owner for any major project decisions that would impact scope or change requiring additional funding.*
33. *Internal/proprietary change log database tracking requester, description, rationale, impacts to other groups, and FF&E costs.*
34. *Mostly, project notes/minutes of O/A meetings.*
35. *We keep a OneNote file that is updated frequently so there is always something to reference.*
36. *Project notes*
37. *We are a small company with the few members performing many roles and many decisions are made on an as needed basis per each members discretion.*
38. *Process varies by project and project team but usually includes sketches, graphics, budgets, and value engineering lists that attempt to catalogue major decisions or changes*
39. *ASIs, PCOs, office wide email*
40. *Meeting notes (standard forms) ...flowed from Architect to contractors depending on project phases.*
41. *Meeting minutes*
42. *Keeping project notes on all projects.*
43. *Memos*
44. *Newforma*
45. *Plans and notes are sent to a centralized team that maintains documents and posts them to a database available for review.*
46. *Email summaries*
47. *Usually meeting minutes.*
48. *Every revision is kept track of, drawings are filed in dated folders, with at least of a brief explanation of the changes as we progress through the projects*
49. *Depending on which phase we are within a given project, RFI, ASI, etc are used. We also use internal checklist. Each design phase has its own checklist. When a design decision is made it should go in that checklist. The checklist is within excel and an external program called teamwork.*
50. *I could write a book on the process, but yes, to sum up this response, all information from initial concept to turnover of construction is/will-be documented in a shared computer drive (reason for construction, justification, preliminary sketches/ideas, drawings, budgets, SOW, bidding, construction, commissioning, etc.)*
51. *Through meeting minutes taken by the Architect.*
52. *Excel and word*
53. *Procore was used through RFIs, submittals and updated project documents.*
54. *.pdf / text documentation created by design team and filed within appropriate job folders on company server.*
55. *We use change orders to document changes.*
56. *Email*
57. *The Facilities Engineering department provides document reviews, annotates the required and recommended changes using spreadsheets and notes on drawings. Most drawings are marked up using BlueBeam Revu or similar PDF markup programs.*
58. *Proprietary system for each individual project.*
59. *through notes or AIA documents and final through documents in the model or drawings*
60. *working at a small scale like we do, it doesn't feel necessary.*
61. *An informal system of meeting minutes which may include design direction is kept, but nothing is maintained throughout the lifetime of the project.*
62. *Procore or blue beam*
63. *Yes, but it is not always consistent depending on which employee was responsible for documenting these changes. Workers are expected to scan in and store all pertinent information on a shared network drive, but it is often overlooked. Any information that is relayed through email is lost very often as many employees fail to move these documents to the drive.*
64. *Frankly, I don't know if it was ever thought of or deemed important. I believe it was expected that project managers did it in some manner (as they saw fit) within their project management role.*

Question 18		
What do you think is the ideal method for documenting key project or design decisions and/or requirement changes? (Please select all that apply)		
Answer Choices	**Responses**	
Project notes	58.54%	72
Spreadsheets	34.96%	43
Generic database (Microsoft Access, etc.)	30.08%	37
Proprietary system	14.63%	18
CAFM or related software	17.07%	21
BIM related software	35.77%	44
Not applicable	6.50%	8
Other (please specify)	9.76%	12
	Answered	**123**
	Skipped	**21**

1. *I don't know, but someone could make a lot of money if they figured this out!*
2. *Building on or developing, training, and fully implemented systems to be used in an organisation.*
3. *Procore*
4. *Drawing set comments & meeting minutes*
5. *By virtue of the pre-agreed milestones initiating client sign off (approval) - any changes post milestones would be subject to the pre-agreed change process & approval would be required ahead of implementation All decisions & changes would be recorded - the process would be pre-agreed & recorded for access by all comers within the PEP - the Project Execution Plan - this can be adapted for use via a generic database, a proprietary system, using cafm or IM software - as is appropriate to the organisation - ideally all would be part of a progressive IM model, however, not every organisation, nor project team, has the knowledge or infrastructure to accommodate an IM at present*
6. *a document that the owner can provide written confirmation or approval*
7. *Office wide presentation*
8. *unsure*
9. *project emails between design principal, owner, relevant consultants*
10. *Have an assistant!*
11. *What makes sense varies by client and project type/size.*
12. *SQL database*

Q19: FM data helpful to share with AE-design

Question 19	
Prior research has suggested that the inclusion of facility managers during design phases leads to better-performing facilities. Based on your professional experience, what facility management/operations related data or information do you believe would be most helpful to provide from FM to A/E design teams?	
1.	*Think about how a system or single item example being a light fixture over a large stairwell will be maintained or accessed in the future. These types of things are easily overlooked by AE-design teams and can be nightmares for maintenance staff to maintain and repair in the future. There are many examples like this.*
2.	*We have a primary owner's rep for every project - All information filters in and out from this single source. I think this model works because we have one project manager that serves as the primary owner's representative. Typically, we review FM from a building support standpoint - who and how will maintain the building. Our MEP trades work with the engineers to make sure the system design will work with current standards and staffing model. Likewise, our Custodial department is involved in building details, like corridor width, outlet locations, custodial room locations, etc... to ensure that the infrastructure is in place to support their cleaning program. Our carpentry and paint trades are involved to review building construction details and finishes. Our PMs are also well versed in FFE (furniture, fixtures, and finishes) and can provide vital feedback related to the best products to use in a higher education environment. Most importantly, our customer is involved from start to finish during the design process. Just as there's a primary PM assigned to interact with all the working parts of the project, there's a primary customer with final approval privileges.*
3.	*Representation with other "owner clients" during programming, schematic design, DD, a CD review, and involvement in pre-award of contracts.*
4.	*Not applicable*
5.	*all data can at some time be crucial so I would like to keep all data, if possible, as built construction drawings are in my opinion the most important to retain*
6.	*Level of competence of facility maintenance department in order to determine ability to maintain more sophisticated systems. Preferred mechanical system types.*
7.	*Current facility maintenance software packages, how they are used and hopes for the updated/new facility, current and proposed staffing, and experience to ensure new facility can be operated with current or proposed staff, discussion of current facilities and issues to be improved, and desired level of technology and variation in materials to simplify operation, cleaning, and maintenance in future.*
8.	*"Constructability" and "Maintainability" and operations and maintenance requirements*
9.	*Maintenance capabilities and experiences. What materials/patterns/techniques last a long time without maintenance.*

10.	*Existing systems design data, shop drawings, T&B reports, controls drawings, current operational concerns.*
11.	*Knowledgeable staff, cost, and common-sense design/operations features.*
12.	*their experience of what employee feedback on internal layout and facility placement has been the most impactful*
13.	*Manufacture O&M publications on equipment preventative maintenance.*
14.	*Build in maintenance into design. Not just something that is "pretty" but design it to last and be maintained as well*
15.	*1. Issues with operation of existing MEP systems. 2. Performance of building envelope materials in existing region/climate. 3. Building energy consumption data. 4. Building automation system data such as trends, logs, and raw data. 5. Lessons learned from other projects related to maintainability and constructability specific to a campus/locality. 6. Availability of skilled labour in locality, as well as market conditions and purchasing power of organisation for skilled labour. 7. Current Tenants and future use of the space. Flexible Architectural and MEP systems can support better constant remodelling and re-use of space. For e.g., a facility housing research laboratories will require flexible systems to support lab renovation projects. As an organisation scientific mission changes, facilities upgrades, or major changes are required to support new S+T instrumentation.*
16.	*Campus standards, as much for tech specs as they can share.*
17.	*How the space is actually used compared to how engineers/designers think the space should be used*
18.	*- Preventative / routine maintenance tasks that are needed to be performed safely. (i.e., maintenance staff working on RTUs, but not having parapets designed at the minimum handrail height by OSHA's standards) - Location of HVAC units located above ACTs. For example, units are sometimes located at heights or in areas that are difficult to manoeuvre during the lifetime of the building to replace filters or work on. - Requirements and follow through of total building commissioning. - Locations of any and all MEP finishes that will be maintained over the lifetime of the building.*
19.	*Maintenance and preventative maintenance records and costs*
20.	*I don't feel I am qualified to answer this as I am not in an A/E or FM design team.*
21.	*NA*
22.	*The end users of the asset are required - or representation thereof - knowledge of the organisational requirements & the FM resource particular to the management of FM (in house or outsourced), the procurement methodology & strategy & the current & future for asset management - paper, CAFM, cloud based - for example - as an absolute minimum*
23.	*I don't know.*
24.	*Materials, accessories specs., EMS, HVAC, landscape designs,*
25.	*programming information and data for space utilization. Information regarding maintenance schedules and budgets to determine the required durability of materials. Any sort of data relating to how the facility's employees utilize the space and what their daily tasks are. Current building mechanical and electrical loads helping to determine energy usage and efficiency with hopes of improving upon net energy consumption.*
26.	*Depends, if the facility manager is a good facility manager and knows everything about the facility and what needs to happen to make the space be successful. Most of the time they do help out a lot with the project especially a lot of areas can be missed on a large job when the focus is centred on where the client will be.*
27.	*not my topic*
28.	*That the Facilities Manager is just as valuable to the team in order to maintain the facilities after many years. The architect and engineers are gone after the project, but the Facilities Manager has to maintain the building and property for many years to come.*
29.	*- Flow of the building/space layout from an operations perspective. A recent example: architects designed a bike room with no access from the exterior for safety concerns. Ops team pointed out location of bike room relative to building lobby entrance and what the means on a rainy day to trapse a wet bike across an entire lobby. Similar situation for the location of a trash compactor room relative to the operations of trash collection. Materials selection is another issue we have seen. We spec beautiful, green materials that aren't maintained well because the Ops team might use bleach on everything and it's too hard to switch out for just one floor. So, understanding the operations side is helpful during the design phase and vice versa.*
30.	*Maintenance staff size and skills to be able to tailor design to the ability to maintain the building, grounds, and equipment.*
31.	*Facility managers have the building history and have interacted with all aspects of a structure. This usually trumps any assumptions that architects/engineers typically make when they are gathering data.*
32.	*Their experience maintaining their facilities and understanding the community's budget restrictions. Most communities build a Cadillac with an escort pocketbook.*
33.	*future Maintenance requirements for staffing skill set of staffing Hours of operation Budget numbers for cost of future maintenance*
34.	*Long term durability of products used in construction and also mechanical equipment used and its needs and accessibility for maintenance*
35.	*1. Realistic projection utility consumption of the proposed design. 2. Understanding of Preventative Maintenance requirements with a focus on technicians having access. 3. Appropriate finishes based on the capacity of the owner's team to properly maintain.*

	4. Controls and technology integration; with a focus on HVAC systems and mechanical packaged units providing the owner with prudent access and management of the systems upon project completion. *5. Review and site inspection of projects 2 to 3 years after substantial completion.*
36.	*A detailed, up-to-date list of all finish specifications, equipment specifications - either embedded in a project manual or utilizing BIM to house this information.*
37.	*Knowledge of daily operations through the facility/campus, as well as knowledge of long-term operations, and previous repairs.*
38.	*How the facility is used. What items are "wrong" in the current facility as well as what works well in the current facility.*
39.	*Ease of maintenance expected requirement life cycle, capacity to maintain critical equipment, capital budgeting and life cycle cost ownership. If one is responsible for funding, one will think twice. Long term planning of space utilization.*
40.	*The knowledge and expertise provided by an on-site individual- saves time and money as this person usually knows the background and intimacies of the facilities.*
41.	*Everyone matters. Post construction maintenance workers are just as important and the people that occupy and work in the building. If something is designed with zero regard for the people that are maintaining it, why would they provide a true effort if they can see they were never accounted for.*
42.	*Long term maintenance budget*
43.	*MEP system requirements, cleaning requirements / methods of products, being open to sustainable design*
44.	*Building standards information (systems, equipment, operations, etc.). Additionally, understanding operational cost implications of design (maintenance, utilities, etc.). Having the discussion of "first cost" versus operational costs, and ROIs is critical. What are the priorities on each individual project.*
45.	*Facility standards manual*
46.	*Facility managers are very helpful for how the company uses the space and what would make their job easier as they are the ones dealing with the issues every day in the space. Their knowledge can lead to better overall design in terms of function.*
47.	*The complexity of operations requirements, level of training, maintenance schedules, hiring practices*
48.	*Easily maintained designs and similar to the currently built buildings.*
49.	*Ensuring design teams consider the long-term maintenance of the facility.*
50.	*What systems cannot be value engineered and deviate from institutional design standards.*
51.	*mechanical controls/performance, access controls, maintenance*
52.	*Design & construction standards.*
53.	*Space use, maintenance records and history and costs*
54.	*The FM in our project is usually brought in after the building is built. And brought in by the developer or client.*
55.	*Organisational Design Standards that say what's acceptable and what's not.*
56.	*How equipment will need to be maintained, installed, and removed. If this isn't done right in the design phase, the equipment may not be able to be maintained appropriately.*
57.	*Product specifications and alternatives. Base drawings.*
58.	*Heating/cooling systems and controls*
59.	*Occupancy, usage/traffic, maintenance, durability, systems*
60.	*Existing As-Built Drawings in electronic format, Revit files if applicable, shop drawings of equipment that is installed in a facility, geotechnical report, site survey*
61.	*Age and functionality of systems as well as locations and descriptions of regular, ongoing building issues*
62.	*Operational cost.* *Maintenance cost* *Replacement cost* *ROI on workflow studies up*
63.	*Maintenance data*
64.	*FMers sometime can look at the bigger picture of the project and they are going to think about things like how are we going to clean, how do those materials clean up, will things need to be redone over time. That big picture view is nice at times. Design teams can sometimes get stuck on just designing something cool and not very user friendly.*
65.	*Materials used with detailed information about the products. Best practice for maintenance*
66.	*More specific building and space use, current facility issues of an existing building, hours of operations, material selections*
67.	*Occupant space needs & design feedback*
68.	*End user needs and wants* *Existing conditions in the space* *As someone in the field, I see the most issues and changes with these two items.*
69.	*how is the facility used on a daily basis, what aspects of the daily operations do they struggle to accomplish, what processes/etc. are worth holding onto, what is the decision-making process.*
70.	*they are able to provide all the needed space requirements up front which allows for a concise and efficient use of space.*
71.	*Lessons Learned for energy efficiency, maintenance accessibility, ease of maintenance for equipment, reliability of equipment, and redundancy of critical equipment*

72.	*Program Structure / Usage Type would be most helpful, I think. Our Firm is small and usually, do not have involvement with many commercial projects and Facility Management teams. So, I am unsure of their exact practices, but this would be my assumption.*
73.	*NA: I work in a residential company.*
74.	*Well document history of changes to the systems over the years and a direction of the future of where the company/owner would like to go with their environments: LEED/wellbeing/energy, etc.*
75.	*Information of what their day-to-day expectations are for the facility. What are they familiar with? What would help them to be more effective?*
76.	*How spaces are used - i.e., is there a card access door that is always propped open.*
77.	*Facility managers help with the little things on how they operate a building. For example, what kind of paper towel dispensers they want; rolled or folded, or if they prefer electric hand dryers. All in all, what design decisions would make their jobs easier when trying to maintain the building and that is very important*
78.	*Data concerning occupancy and use of space, as well as utility costs, prove to be extremely useful.*

Q20: FM data helpful to share with AE-design

Question 20											
How useful would the following facility management/operations data categories be to A/E design teams during the design process? (Please provide additional answers as needed)											
Answer Choices	**Extremely Useful**		**Very Useful**		**Somewhat Useful**		**Not so Useful**		**Not at all Useful**		**Total**
Janitorial unit costs	11.43%	12	20.95%	22	33.33%	35	23.81%	25	10.48%	11	105
Janitorial cleaning frequency	18.10%	19	35.24%	37	32.38%	34	8.57%	9	5.71%	6	105
Maintenance unit costs - corrective	28.85%	30	29.81%	31	32.69%	34	5.77%	6	2.88%	3	104
Maintenance unit costs - scheduled	26.42%	28	37.74%	40	27.36%	29	5.66%	6	2.83%	3	106
Maintenance unit costs - exceptional	20.19%	21	31.73%	33	35.58%	37	9.62%	10	2.88%	3	104
Occupancy and use (space utilization)	66.98%	71	27.36%	29	5.66%	6	0.00%	0	0.00%	0	106
Operational unit costs	36.79%	39	39.62%	42	19.81%	21	1.89%	2	1.89%	2	106
Facility or employee productivity	31.13%	33	33.02%	35	23.58%	25	8.49%	9	3.77%	4	106
Staffing or employee labour unit costs	18.10%	19	29.52%	31	29.52%	31	18.10%	19	4.76%	5	105
Employee or customer/user satisfaction	41.51%	44	35.85%	38	16.98%	18	4.72%	5	0.94%	1	106
Utility or energy consumption and/or unit costs	58.49%	62	34.91%	37	5.66%	6	0.94%	1	0.00%	0	106
Other (please specify)											7
									Answered		**106**
									Skipped		**38**

1. *I manage a facility so all of those items I feel are important*
2. *Not able to specify the above based on my experience*
3. *There are too many categories to list - a complete interface with building services is critical*
4. *Note - not all clients will have this data - a standalone new build for example - not all clients will care - the commercial developer*
5. *not my topic*
6. *Spectrum of performance vs. cost and appearance. Schools shouldn't have expensive and hard to maintain elements to deal with after the occupancy period begins.*
7. *All these are good but are only somewhat useful to an architect and the client. In our line of work, cost of a project is what drives the deliverables. Yes, these areas may be great to consider, but the overall building and making for the client gets what they desire is more important. (Especially in a mixed-use affordable housing project)*

Q21: Digital exchange of information

Question 21		
Do you agree or disagree with the following statement: The digital exchange of facility data and information would be sufficient to realize the potential benefits of facility management inclusion during design (that person-to-person interaction is not necessary)?		
Answer Choices	**Responses**	
Strongly agree	7.96%	9
Agree	19.47%	22
Neither agree nor disagree	7.96%	9
Disagree	23.89%	27
Strongly disagree	34.51%	39
No opinion	2.65%	3
Other (please specify)	3.54%	4
1. *Changing technology will also require training infrastructure, funding of that infrastructure, and ongoing professional development to keep the facilities operating as intended.* 2. *There needs to be face and face with the building designers from a facility manager perspective.* 3. *Digital exchanges would be extremely beneficial but may require some explanation of the data once received by designers. Interpreting building management data could be cumbersome and difficult if not utilized frequently.* 4. *Agree - but only so far as being contingent on the semantic use of the REALIZING the potential benefits, and not to go so far as to utilize them.*	**Answered** **Skipped**	**113** 31

Q22 – Q23: AE-design decision rationale shared with FM/O

Question 22		
Do you agree or disagree with the following statement: A/E design rationale provided to facility management and operation teams would be beneficial to the facility operation and maintenance process?		
Answer Choices	**Responses**	
Strongly agree	39.82%	45
Agree	46.90%	53
Neither agree nor disagree	2.65%	3
Disagree	3.54%	4
Strongly disagree	3.54%	4
No opinion	1.77%	2
Other (please specify)	1.77%	2
1. *I would agree only if Facility Management and operation teams had an opportunity to provide input early on and throughout the design process.* 2. *Whenever I built a project without the involvement of the future occupants, the FM ops personnel, the building was an orphan, maintenance was poor. There is one thing worse than having an insistent owner, that's having none at all.*	**Answered** **Skipped**	**113** **31**

Question 23		
Do you agree or disagree with the following statement: Awareness of the rationale behind facility design decisions is necessary to effectively evaluate a facility's performance and design quality?		
Answer Choices	**Responses**	
Strongly agree	41.96%	47
Agree	44.64%	50
Neither agree nor disagree	5.36%	6
Disagree	3.57%	4
Strongly disagree	2.68%	3
No opinion	0.00%	0
Other (please specify)	1.79%	2
1. *The initial stage. (Feasibility)* 2. *If it were done, I would agree.*	**Answered** **Skipped**	**112** **32**

Q24: Project stages to share data from FM to AE-design

Question 24		
During which project stages would it be most useful to transmit data and information FROM facility management/operations TO architecture/engineering design teams? (Please select all that apply)		
Answer Choices	**Responses**	
Project definition – determining project feasibility	54.95%	61
Project planning/programming (PD)	82.88%	92
Schematic design (SD)	72.97%	81
Design development (DD)	67.57%	75
Construction documentation (CD)	34.23%	38
Construction administration (CA)	27.03%	30
Project closeout and warranty	37.84%	42
Project commissioning	36.04%	40
I do not think there is a need to involve facility management in design during any project stage	0.00%	0
No opinion	0.90%	1
Other (please specify)	4.50%	5
1. *Post-Occupancy* 2. *One year after occupancy* 3. *Concept design* 4. *It is more appropriate and likely to yield positive outcomes if facility management/operations are included in the design process through all stages of project definition through the completion of project commissioning.* 5. *DD and CD phases are too late to incorporate FM information because at that time project feasibility has been determined along with project budget and FM information at that point could make or break a project from moving forward.*	**Answered** **Skipped**	111 31

Q25: Project stages to share data from AE-design to FM

Question 25		
During which project stages would it be most useful to transmit data and information TO facility management/operations FROM architecture/engineering design teams? (Please select all that apply)		
Answer Choices	**Responses**	
Project definition – determining project feasibility	40.71%	46
Project planning/programming (PD)	61.06%	69
Schematic design (SD)	61.95%	70
Design development (DD)	60.18%	68
Construction documentation (CD)	49.56%	56
Construction administration (CA)	44.25%	50
Project closeout and warranty	61.95%	70
Project commissioning	51.33%	58
I do not think there is a need to involve facility management in design during any project stage	0.88%	1
No opinion	1.77%	2
Other (please specify)	1.77%	2
1. *Depends on the project & program I would suggest* 2. *It is more appropriate and likely to yield positive outcomes if A/E professional include facility management/operations in the design process through all stages of project definition charettes through the completion of training and project commissioning.*	**Answered** **Skipped**	113 31

Q26 – Q28: Respondent familiarity with and use of various building classification systems

Question 26											
How familiar are you with the following building systems classification systems? (Please select all that apply)											
Answer Choices	**Not at all Familiar**		**Slightly Familiar**		**Somewhat Familiar**		**Moderately Familiar**		**Very Familiar**		**Total**
OmniClass (OCCS)	81.55%	84	8.74%	9	5.83%	6	1.94%	2	1.94%	2	103
MasterFormat	42.45%	45	15.09%	16	9.43%	10	16.98%	18	16.04%	17	106
UniFormat	70.30%	71	9.90%	10	5.94%	6	4.95%	5	8.91%	9	101
Uniclass	83.33%	85	11.76%	12	1.96%	2	1.96%	2	0.98%	1	102
IFC (Industry Foundation Classes)	73.08%	76	13.46%	14	8.65%	9	2.88%	3	1.92%	2	104
COBie (Construction-Operations Building Information Exchange)	73.33%	77	12.38%	13	10.48%	11	3.81%	4	0.00%	0	105
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	92.31%	96	5.77%	6	0.00%	0	0.96%	1	0.96%	1	104
CAWS (Common Arrangement of Work Sections)	90.38%	94	8.65%	9	0.00%	0	0.00%	0	0.96%	1	104
NRM (New Rules of Measurement)	94.23%	98	4.81%	5	0.00%	0	0.96%	1	0.00%	0	104
a Proprietary system	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0
Other (please specify)											1
1. *not my topic*									**Answered**		**106**
									Skipped		**30**

Question 27										
Which of the following building systems classification systems do you regularly use (or have regularly used)? (Please select all that apply)										
Answer Choices	Never (0% of the time)	Rarely (less than 10% of the time)	Occasionally (about 30% of the time)	Sometimes (about 50% of the time)	Frequently (about 70% of the time)	Usually (about 90% of the time)	Always (100% of the time)	I do not know	Not applicable	**Total**
OmniClass (OCCS)	76	7	2	0	2	0	1	9	4	101
MasterFormat	43	11	5	2	3	10	16	9	4	103
UniFormat	66	10	1	1	2	4	3	9	4	100
Uniclass	79	5	1	0	1	0	0	9	5	100
IFC (Industry Foundation Classes)	72	7	2	3	2	0	0	9	5	100
COBie (Construction-Operations Building Information Exchange)	77	5	3	2	0	0	0	9	5	101
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	80	5	1	0	1	0	1	8	5	101
CAWS (Common Arrangement of Work Sections)	80	6	0	0	0	0	0	9	5	100
NRM (New Rules of Measurement)	81	4	0	2	0	0	0	9	5	101
a Proprietary system	59	3	3	4	2	0	2	11	6	90
Other (please specify)										2
1. *I do not know what any of the above items are or what they are used for* 2. *not my topic*									**Answered**	**104**
									Skipped	**40**

Q28: Effective methods to transmit data between FM and AE-design

Question 28											
To what extent do you think each of the following represents an effective method for transmitting data and information between facility management/operations and architecture/engineering design teams? (Please select all that apply)											
Answer Choices	**Extremely Effective**		**Very Effective**		**Somewhat Effective l**		**Not so Effective**		**Not at all Effective**		**Total**
OmniClass (OCCS)	2.08%	2	2.08%	2	5.21%	5	0.00%	0	1.04%	1	66.67%
MasterFormat	5.15%	5	11.34%	11	13.40%	13	0.00%	0	1.03%	1	47.42%
UniFormat	3.16%	3	2.11%	2	7.37%	7	0.00%	0	1.05%	1	64.21%
Uniclass	1.05%	1	1.05%	1	3.16%	3	0.00%	0	1.05%	1	69.47%
IFC (Industry Foundation Classes)	1.05%	1	3.16%	3	6.32%	6	0.00%	0	1.05%	1	66.32%
COBie (Construction-Operations Building Information Exchange)	1.04%	1	4.17%	4	6.25%	6	0.00%	0	1.04%	1	64.58%
CI/SfB (Construction Index/ Samarbetskommitten for Byggnadsfragor)	2.11%	2	0.00%	0	1.05%	1	1.05%	1	1.05%	1	70.53%
CAWS (Common Arrangement of Work Sections)	1.05%	1	0.00%	0	1.05%	1	0.00%	0	2.11%	2	71.58%
NRM (New Rules of Measurement)	1.04%	1	0.00%	0	2.08%	2	0.00%	0	1.04%	1	71.88%
a Proprietary system	4.26%	4	1.06%	1	3.19%	3	0.00%	0	2.13%	2	63.83%
Other (please specify)											5
									Answered		**97**
									Skipped		**47**

1. *Once again, I do not know what any of the above items are or what they are used for*
2. *Not really sure since we do not use them*
3. *not my topic*
4. *A summary of the materials, equipment, and control systems is most appropriate, specifications are not effective for this purpose.*
5. *Do not have a broad enough background of options to answer this.*

Q 29: Transfer of data from between FM/O and AE-design teams

Question 29		
Which of the following mechanisms do you think would encourage the transfer of data and information between facility management/operations and architecture/engineering design teams? (Please select all that apply)		
Answer Choices	**Responses**	
Building Performance Evaluations (PBE)	53.10%	60
Facility commissioning	48.67%	55
Including facility managers during project program development	77.88%	88
Including facility managers in design and construction phase project meetings	76.11%	86
Including facility managers in the writing of performance specifications	48.67%	55
Post Occupancy Evaluations (POE)	65.49%	74
Providing a mechanism for the easy transfer of digital data or information between FM and A/E design teams	46.02%	52
Requiring BIM deliverables to be handed over to facility managers or owners	53.10%	60
Requiring COBie submittals to be handed over to facility manager or owner	11.50%	13
Requiring IFC submittals to be handed over to facility managers or owners	13.27%	15
Soft Landings or other project data exchange requirements (ex. Operations and Maintenance Support Information (OMSI))	15.04%	17
I do not think there is a need to increase the transfer of data and information between facility management/operations and architecture/engineering design teams?	0.00%	0
No opinion	7.96%	9
Other (please specify)	3.54%	4
	Answered	**113**
	Skipped	**31**

1. *This is my best guess considering that most of the above I have never dealt with before*
2. *have contractor (CM) turn over O&M content in a format that can be uploaded into the owner's work order management/inventory equipment system*
3. *For this to be effective I would have to see a substantial increase in the ability to use technology.*
4. *The introduction of the other systems may be very valuable, but no experience in their use.*

Q30: Additional Comments

Question 30: Additional comments shared by respondents	
1	*In my opinion the earlier and more frequently an FM professional is included in the design process the better the building will be for the owner/user group.*
2.	*There's nothing as boring as a finished project.*
3.	*I think a more integrative approach to design has a great deal of merit and has the potential to develop buildings that truly go beyond the star architect approach and really begin to look at building design from a lifetime perspective. However, it seems to me that there is a long way to go to bring architecture from its traditional form to my vision. I have always been amazed that in my experience has shown that there has been very little work in Post Occupancy Evaluation of any kind. I believe that the power of the "I" in BIM has enormous potential for both designers and FM and ultimately for the owner as the building matures but it will take a substantial increase of all to put information into the model and to get it out. The matter of getting it out is also complicated by continued advancement in technology that very quickly makes the information that exists of little use because it is outdated.*
4.	*without the involvement of FM in the design phase, it can lead to a very costly redesign once the employees give their feedback*
5.	*Having a complete preventative maintenance program will prevent long term cost.*
6.	*Facility Management can bring a unique field perspective to A/E design teams, contribute to the design process, and improve the final product. Constructing maintainable facilities is often second to maintaining the design vision of a project or the aesthetic outcome the A/E has envisioned. Ideally the FM team needs to comprise architects and engineers that specialize in constructability and maintainability and essentially act as the grounding rod for the design A/E.*
7.	*The facility manager is the one to take care of the building and make sure it runs properly. They need to know the building intimately. Before the project even gets started the design team should include the FM. The FM is the one who knows what is actually needed and what would work best for the people in their building.*
8.	*The profile of FM needs to be raised - this is a profession - a challenging & rewarding profession; sadly, even other built environment professionals perceive this role to revolve about reactive emergency maintenance - the person with the broom & bucket*
9.	*The earlier in the process facility managers are involved, including data transferring, the more information designers have to create a space that functions well for the client. However, this could also cause a reduction in creativity during early design stages. Balance is the key to any situation and having a facility manager at meetings can help to guide designers on a meaningful and efficient path to a successful building.*
10.	*A grounded, experienced and well-spoken facilities manager is the key to effective design for the client. In my case, the school district. We are in between the vision and the actual use of any project.*
11.	*Designers often are not in touch with the realistic expectations of occupant administrations, leaving FMs in poor positions in regard to efficiently maintaining the new assets within the constraints of budgets that are driven primarily by goals other than building maintenance*
12.	*Understanding the intended lifespan of a facility and also the maintenance needs, energy efficiency needs and other requirements (values) of the owner drive many of the design decisions from all aspects of the project.*
13.	*The biggest disconnect I've seen is when "maintenance and operations" are not a part of the same team as the planning and or construction teams. When they are all under one umbrella, the communication is much better. The other organisation setup starts to create silos (especially in larger organisations). It's more of a project "hand-off" at that point. One group builds it, the other then gets handed the keys and is responsible for maintaining (which isn't great).*
14.	*Training during commissioning and CA would be useful as well as discussions about the complexity of controls during design*
15.	*I think that FM field needs to be included more in the entire process of construction and/or renovations. From a supplier side, I question a lot of designs with a FM degree/background.*
16.	*In my experience the most successful projects have been those that have turned over to Operations/FM, in which have had FM involvement during the design phase. As a current FM and a former PM, FM's ultimately hold the keys at the end of the day and control the operations. PM and FM interaction during design is a key relationship for a successful building.*
17.	*I always believed the architectural design process is supposed to solve problems or needs of the institution. When facility management has not been involved in the design and decision-making process the design has a tendency to create problems and solve them. Which is contradictory to the design process.*
18.	*I think that FM individuals are vital in the design process. I do not see it often enough in the CM/estimating process and think that it would create buildings with longer lifestyles. I believe A/E’s, FM, CM and Owner should be on board with the project and design from day 1.*
19.	*Facility Management should be involved in each stage of design and construction, however, each party involved should recognize their own knowledge set and relevancy during projects.*
20.	*From a general contractor’s standpoint, when we get the project, it often seems the architecture firm hasn't consulted at all with end users and what they want. Of course, there are several rules in places to limit end users and what they want but certainly more interaction through design and construction would be helpful.*
21.	*The more the facility Manager is involved the better the outcome will be for all parties.*
22.	*The best FMs understand the design process. The best designers understand the operations/maintenance process for buildings. The design process becomes petty and adversarial when uninformed designers and FMs hunker down in their own silos.*

Appendix G: Online Questionnaire Statistical Significance Formulas

To calculate the statistical significance between groups, the following formulas were used:

Statistic	Description	Formula
a1	The proportion of the first group answering a question a certain way multiplied by the sample size of that group.	$a_1 = p_1 * n_1$
b1	The proportion of the second group answering a question a certain way multiplied by the sample size of that group.	$b_1 = p_2 * n_2$
Pooled Sample Proportion (p)	The combination of the two proportions for both groups.	$p = \frac{a_1 + b_1}{n_1 + n_2}$
Standard Error (SE)	A measure of how far your proportion is from the true proportion. A smaller number means the proportion is close to the true proportion, a larger number means the proportion is far away from the true proportion.	$SE = \sqrt{(p * (1 - p)) * (\frac{1}{n_1} + \frac{1}{n_2})}$
Test Statistic (t)	A t-statistic. The number of standard deviations a number is away from the mean.	$t = \frac{p_1 - p_2}{SE}$
Statistical Significance	If the absolute value of the test statistic is greater than 1.96* standard deviations of the mean, then it's considered a statistically significant difference.	$\|t\| > 1.96$

Appendix H: Classification System Online Questionnaire

FM/O - AE Knowledge Sharing Categories

Survey Introduction

This survey seeks your opinion pertaining to a proposed classification system for improving knowledge sharing between facility management/building operations (FMO) and architecture/engineering (AE) design teams. While this survey follows a prior questionnaire, it is not necessary to complete the previous survey to provide input here.

The researcher is interested in your opinion on how to classify FMO knowledge in a manner that makes it more accessible to AE teams. Prior research finds the inclusion of FMO expertise improves AE design processes; however, barriers exist that hinder the consideration of FMO expertise during AE design. This study proposes that for AE design to take full advantage of FMO knowledge, it is necessary to structure FMO knowledge in a manner that makes it more accessible and is compatible with the AE design process.

While many systems exist to classify AE/FMO related information (such as MasterFormat, UniClass, COBie, etc.), existing systems lack in their ability to support the classification and sharing of KNOWLEDGE vs. INFORMATION between FMO and AE design. In this regard, the following questionnaire solicits views on how to classify FMO knowledge in a manner that is more accessible to AE design teams.

This questionnaire takes approximately 5 minutes to complete. Your opinions are essential in developing this work and are much appreciated. Please answer the following questions to the best of your ability based on your professional experience and opinions. You may skip questions as you wish. All responses will be anonymous, but if you would like to see the results of the survey, or participate in future related research, you may include your email at the end of the questionnaire.

Thank you,

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FM/O - AE Knowledge Sharing Categories

Informed Consent for Participation in the Study

Please read the following and acknowledge your informed consent below before completing the following survey.

Project Title: Improving architecture and engineering design decisions through the transfer of facility management and operations knowledge, information, and data to architecture and engineering design teams.

Contact Information

Principal Investigator:
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Research Supervisor:
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Project Details: You are invited to participate in an online survey investigating the integration of facility management (FM) expertise into architectural/engineering (AE) design processes. Researchers are interested in identifying the perceived benefits of integrating facility management and operations (FMO) expertise in design as well as investigating barriers limiting such integration. **We estimate it will take approximately 5 minutes to answer the survey questions.** You may refuse to answer any question at any time without consequence. If you do not wish to answer a question, you may skip any question(s) you choose or exit the survey at any time. However, please be aware that responses that have been made up to the point of exit will not be withdrawn – if you wish to 'erase' previous responses before exiting the survey, you will need to backtrack through the survey.

Benefits of Participation: Information collected will indirectly benefit facility management and architecture/engineering design professionals by helping identify opportunities for the disciplines to work more effectively together. The survey data will be collected anonymously, and the topic is not sensitive. The data will be used to inform academic publications. Participation or nonparticipation in this study will not impact your relationship with the University of Salford or researchers in any way.

Compensation: Compensation will not be provided for participation in this survey.

Risks: Participation in this survey presents no greater risk than what one encounters in daily life.

Confidentiality and Anonymity: Your contributions to the project will be treated with confidence and your data will be held and used on an anonymous basis. Your responses to this survey will not be used other than for the purposes described above and third parties will not be allowed access to them (except as required by the law). Your data will be held in accordance with relevant laws and regulations. You will not be personally identifiable in any of the output from this survey. The results of this study may be published in research articles but will not include any information that would identify you.

Further Questions or Complaints: If you have questions about this study, please contact the Principal Investigator listed above. If you have questions about your rights as a participant, would like to file a complaint, or if you would like to discuss with someone else at the University of Salford, please contact the School of the Built Environment Research Ethics Panel at S&T-ResearchEthics@salford.ac.uk, or at +44 0161 295 5278. You may also contact the research supervisor, Dr. Paul Coates, regarding any additional questions at s.p.coates@salford.ac.uk, or at +44(0) 0161.295.2165.

* 1. **Participant's Statement of Informed Consent:**
I voluntarily agree to participate and to the use of my data for the purposes specified above. I am aware that I can withdraw consent at any time by contacting the research team.

Clicking on "**Agree**" below indicates you have read and understood the information about the project and that you voluntarily consent to participate in this research. Participation may be withdrawn at any time without giving reason and without prejudice.

If you do not wish to participate in the research study, please decline participation by clicking on the "**Disagree**" button.

- ◯ Agree
- ◯ Disagree

FM/O - AE Knowledge Sharing Categories

Background Information

2. Which of the following most accurately describes the discipline(s) in which you currently work or have previously worked?

(Please select all that apply.)

- [ ] Architecture or Engineering related design disciplines (AE)
- [ ] Facility Management, Operations, and Maintenance (FMO)
- [ ] Construction
- [ ] Other (please specify)

3. How long have you worked professionally in the discipline(s) identified above?

- ( ) Less than one year
- ( ) 2 – 5 years
- ( ) 5 – 10 years
- ( ) 10 – 20 years
- ( ) More than 20 years

Other (please specify)

FM/O - AE Knowledge Sharing Categories

The following question relates to a proposed FMO knowledge classification system that seeks to improve the sharing of knowledge and expertise between FMO and AE design teams. While many systems exist to classify AE/FMO related information (such as MasterFormat, UniClass, COBie, etc.) these systems classify building-related information but NOT knowledge.

This inquiry is based on the premise that for knowledge to be shared effectively it must be structured in a manner that is accessible and compatible with others within a knowledge community. To this end, this research seeks to classify FMO knowledge in a manner that makes it more accessible and useable to AE design teams.

If you work in an FM related field, can you please identify how useful each of the following knowledge classification categories would be in regard to classifying your knowledge and experiences in a manner that is accessible by AE design teams? You may also think of these categories in terms of how well they categorize your knowledge and experiences that might pertain to AE design. Please feel free to add any comments or to propose additional categories as you see fit.

If you work in and AE design or a construction-related field, can you please evaluate each of the following knowledge classification categories in regard to how useful it would be to receive knowledge, information, and data from FMO in these areas? Please feel free to also add comments or to propose additional categories as you see fit.

4. **FM/O - AE Knowledge Sharing Classification Categories - Part I**

	Very useful (3)	Somewhat useful (2)	Not so useful (1)	Not at all useful (0)
FM/O Capabilities (Knowledge, skill, capacity of FMO staff, etc.)	○	○	○	○
Cost (Life cycle cost-related information, implications, etc.)	○	○	○	○
Design (Design standards, performance specifications, etc.)	○	○	○	○
Energy and Utilities (Utility use and consumption, unit costs, etc.)	○	○	○	○
Equipment and Systems (Existing equipment, systems, FF&E, etc.)	○	○	○	○

Comments (please provide any relevant/related comments here)

5. FM/O - AE Knowledge Sharing Classification Categories - Part II

	Very useful (3)	Somewhat useful (2)	Not so useful (1)	Not at all useful (0)
Materials (Preferred, commonly used, accessible, attic stock, etc.)	○	○	○	○
Operations and Maintenance (O&M procedures, service contracts, etc.)	○	○	○	○
Risk (Mitigation strategies or concerns, etc.)	○	○	○	○
Space (Space use, occupancy rates, utilisation, etc.)	○	○	○	○
User Experiences (User or occupant experiences, etc.)	○	○	○	○

Comments (please provide any relevant/related comments here)

6. FM/O - AE Knowledge Sharing Classification Categories - Part III

	Very useful (3)	Somewhat useful (2)	Not so useful (1)	Not at all useful (0)
Security (Requirements, procedures, etc.)	○	○	○	○
Health and Safety (Requirements, procedures, etc.	○	○	○	○
Sustainability (Requirements, procedures, etc.)	○	○	○	○
Emergency Preparedness/Resiliency (Requirements, procedures, etc.)	○	○	○	○
Codes and Regulations (Local codes, regulations, requirements, etc.)	○	○	○	○

Comments (please provide any relevant/related comments here)

7. Do you have any other ideas for additional FM/0 knowledge classification categories that you can add or would like to share?

FM/O - AE Knowledge Sharing Categories

Survey Conclusion

If you would like to see the results of this study or be updated about its findings and further related research work, please click on the following link to be led to an anonymous email entry page. Your email will be kept separately and will remain anonymous from your answers submitted in this survey.

Anonymous Email Entry

Thank you for your time and for your willingness to complete this survey. Your opinions and answers to these questions are much appreciated and will be helpful in completing this research.

Thank you,

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Appendix I: Classification System Online Questionnaire Raw Data

Q1: Respondent consent

Question 1		
Participant's Statement of Informed Consent: I voluntarily agree to participate and to the use of my data for the purposes specified above. I am aware that I can withdraw consent at any time by contacting the research team. Clicking on "Agree" below indicates you have read and understood the information about the project and that you voluntarily consent to participate in this research. Participation may be withdrawn at any time without giving reason and without prejudice. If you do not wish to participate in the research study, please decline participation by clicking on the "Disagree" button.		
Answer Choices	**Responses**	
Agree	100.00%	34
Disagree	0.00%	0
	Answered	**34**
	Skipped	**0**

Q2: Respondent background

Question 2		
Which of the following most accurately describes the discipline(s) in which you currently work or have previously worked? (Please select all that apply.)		
Answer Choices	**Responses**	
Architecture or engineering related design disciplines (AE)	58.82%	20
Facility Management, Operations, and Maintenance (FMO)	52.94%	18
Construction	26.47%	9
Other (please specify)	8.82%	3
Governmental Oversight of Public Construction Project Management Real Estate Mngt	**Answered**	**34**
	Skipped	**0**

Q3: Years or professional experience

Question 3		
How long have you worked professionally in the discipline(s) identified above?		
Answer Choices	**Responses**	
Less than one year	2.94%	1
2 – 5 years	44.12%	15
5 – 10 years	11.76%	4
10 – 20 years	32.35%	11
More than 20 years	8.82%	3
Other (please specify)		0
	Answered	**34**
	Skipped	**0**

Questions 4 – 6:

If you work in an FM related field, can you please identify how useful each of the following knowledge classification categories would be in regard to classifying your knowledge and experiences in a manner that is accessible by AE-design teams? You may also think of these categories in terms of how well they categorize your knowledge and experiences that might pertain to AE-design. Please feel free to add any comments or to propose additional categories as you see fit.

If you work in and AE-design or a construction-related field, can you please evaluate each of the following knowledge classification categories in regard to how useful it would be to receive knowledge, information, and data from FMO in these areas? Please feel free to also add comments or to propose additional categories as you see fit.

Q4: FM/O - AE knowledge sharing classification categories - Part I

Question 4										
FM/O - AE Knowledge Sharing Classification Categories - Part I										
	Very useful (3)		**Somewhat useful (2)**		**Not so useful (1)**		**Not at all useful (0)**		**Total**	**Weighted Average**
FM/O Capabilities (Knowledge, skill, capacity of FMO staff, etc.)	57.58%	19	36.36%	12	6.06%	2	0.00%	0	33	2.52
Cost (Life cycle cost-related information, implications, etc.)	63.64%	21	36.36%	12	0.00%	0	0.00%	0	33	2.64
Design (Design standards, performance specifications, etc.)	84.85%	28	15.15%	5	0.00%	0	0.00%	0	33	2.85
Energy and Utilities (Utility use and consumption, unit costs, etc.)	45.45%	15	51.52%	17	3.03%	1	0.00%	0	33	2.42
Equipment and Systems (Existing equipment, systems, FF&E, etc.)	60.61%	20	39.39%	13	0.00%	0	0.00%	0	33	2.61
Comments (please provide any relevant/related comments here)									2	
1. *Maybe you consider it as part of another group, but what about maintenance and durability? Perhaps this is Design, but I find the term design too generic and confusing.*									**Answered**	**33**
2. *All 5 categories are integral*									**Skipped**	**1**

Question 4: FM/O - AE Knowledge Sharing Classification Categories - Part I														
	Very useful (3)			**Somewhat Useful (2)**			**Not so Useful (1)**			**Not at all Useful (0)**			**AE Weighted Average**	**FM Weighted Average**	**Total Weighted Average**
	AE	**FM**	**All**	**AE**	**FM**	**All**	**AE**	**FM**	**All**	**AE**	**FM**	**All**			
FM/O Capabilities (Knowledge, skill, capacity of FMO staff, etc.)	50%	82%	59.4%	40%	18%	34.3%	10%	0%	6.3%	0%	0%	0%	2.4	2.82	2.53
Cost (Life cycle cost-related information, implications, etc.)	55%	71%	62.5%	45%	29%	37.5%	0%	0%	%	0%	0%	0%	2.55	2.71	2.63
Design (Design standards, performance specifications, etc.)	90%	82%	84%	10%	18%	16%	0%	0%	0%	0%	0%	0%	2.9	2.82	2.84
Energy and Utilities (Utility use and consumption, unit costs, etc.)	35%	59%	47%	60%	41%	50%	1%	0%	3%	0%	0%	0%	2.3	2.59	2.44
Equipment and Systems (Existing equipment, systems, FF&E, etc.)	45%	82%	60%	55%	18%	40%	0%	0%	0%	0%	0%	0%	2.45	2.82	2.59
Additional written comments:	**AE:** Maybe you consider it as part of another group, but what about maintenance and durability? Perhaps this is Design, but I find the term design too generic and confusing. **FM:** All 5 categories are integral.														

Q5: FM/O - AE knowledge sharing classification categories - Part II

Question 5										
FM/O - AE Knowledge Sharing Classification Categories - Part II										
	Very useful (3)		Somewhat useful (2)		Not so useful (1)		Not at all useful (0)		Total	Weighted Average
Materials (Preferred, commonly used, accessible, attic stock, etc.)	45.45%	15	51.52%	17	3.03%	1	0.00%	0	33	2.42
Operations and Maintenance (O&M procedures, service contracts, etc.)	54.55%	18	33.33%	11	12.12%	4	0.00%	0	33	2.42
Risk (Mitigation strategies or concerns, etc.)	42.42%	14	51.52%	17	6.06%	2	0.00%	0	33	2.36
Space (Space use, occupancy rates, utilisation, etc.)	54.55%	18	42.42%	14	3.03%	1	0.00%	0	33	2.52
User Experiences (User or occupant experiences, etc.)	45.45%	15	48.48%	16	6.06%	2	0.00%	0	33	2.39
Comments (please provide any relevant/related comments here)									1	
These are some of the "must be shared" categories									Answered	33
									Skipped	1

Question 5: FM/O - AE Knowledge Sharing Classification Categories - Part II														
	Very useful (3)			Somewhat Useful (2)			Not so Useful (1)			Not at all Useful (0)			AE Weighted Average	FM Weighted Average	Total Weighted Average
	AE	FM	All	AE	FM	All	AE	FM	All	AE	FM	All			
Materials (Preferred, commonly used, accessible, attic stock, etc.)	40%	59%	44%	55%	41%	53%	5%	0%	3%	0%	0%	0%	2.35	2.59	2.41
Operations and Maintenance (O&M procedures, service contracts, etc.)	35%	88%	56%	45%	12%	31%	20%	0%	13%	0%	0%	0%	2.15	2.88	2.44
Risk (Mitigation strategies or concerns, etc.)	35%	59%	44%	60%	35%	50%	5%	6%	6%	0%	0%	0%	2.3	2.53	2.38
Space (Space use, occupancy rates, utilisation, etc.)	65%	47%	56%	30%	53%	41%	5%	0%	3%	0%	0%	0%	2.6	2.47	2.53
User Experiences (User or occupant experiences, etc.)	50%	41%	47%	45%	53%	47%	5%	6%	6%	0%	0%	0%	2.45	2.35	2.41
Additional written comments:	**AE:** **FM:** These are some of the "must be shared" categories.														

Q6: FM/O - AE knowledge sharing classification categories - Part III

Question 6											
FM/O - AE Knowledge Sharing Classification Categories - Part III											
	Very useful (3)		**Somewhat useful (2)**		**Not so useful (1)**		**Not at all useful (0)**	**Total**	**Weighted Average**		
Security (Requirements, procedures, etc.)	57.58%	19	27.27%	9	15.15%	5	0.00%	0	33	2.42	
Health and Safety (Requirements, procedures, etc.	66.67%	22	33.33%	11	0.00%	0	0.00%	0	33	2.67	
Sustainability (Requirements, procedures, etc.)	57.58%	19	39.39%	13	3.03%	1	0.00%	0	33	2.55	
Emergency Preparedness/Resiliency (Requirements, procedures, etc.)	51.52%	17	39.39%	13	9.09%	3	0.00%	0	33	2.42	
Codes and Regulations (Local codes, regulations, requirements, etc.)	69.70%	23	21.21%	7	9.09%	3	0.00%	0	33	2.61	
Comments (please provide any relevant/related comments here)									1		
In the areas of codes and regs: when following a code will violate any of these 5 categories, a best practice solution must be sought through an appeal process.									**Answered**	**33**	
									Skipped	**1**	

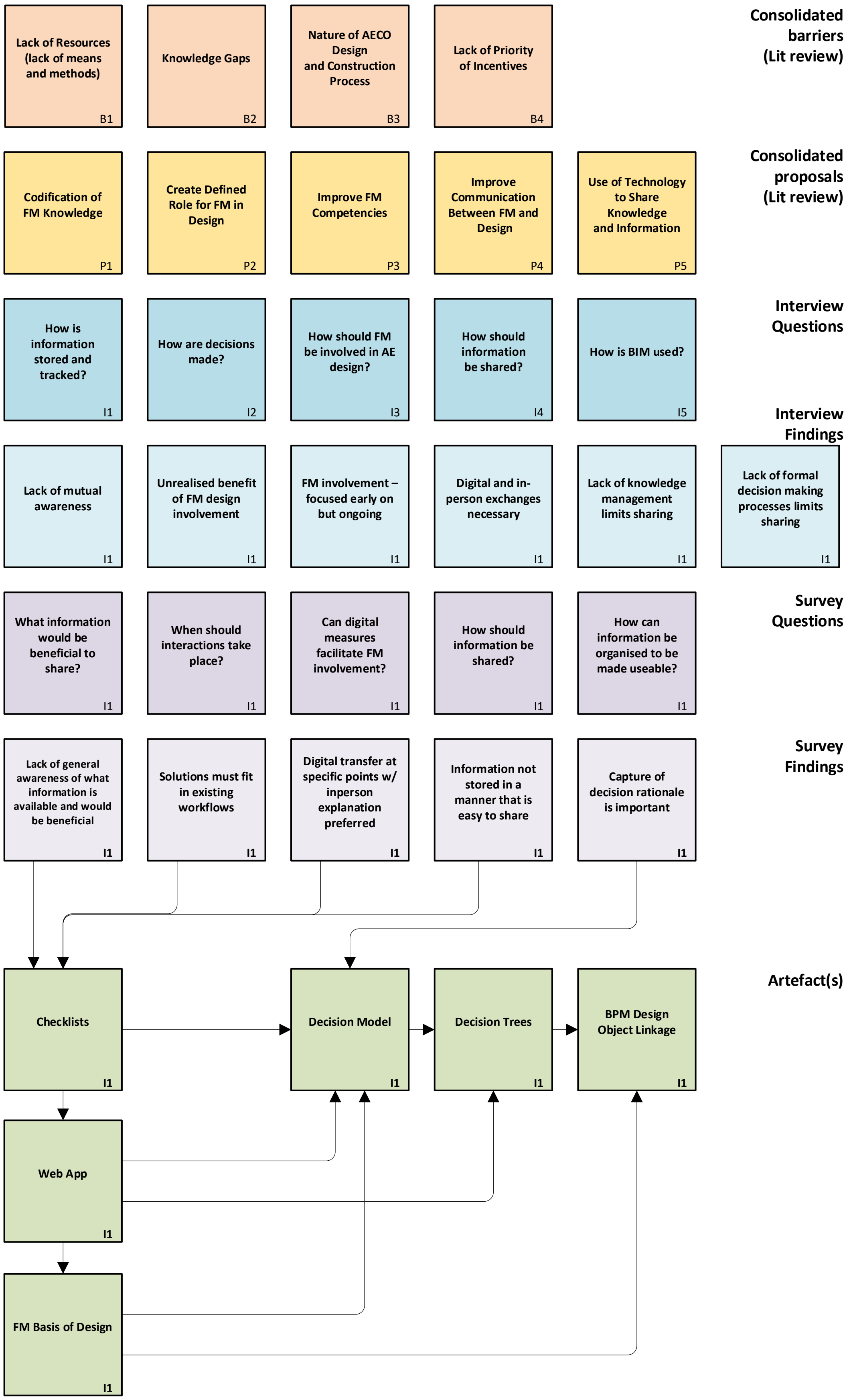
Question 6: FM/O - AE Knowledge Sharing Classification Categories - Part III															
	Very useful (3)			**Somewhat Useful (2)**			**Not so Useful (1)**			**Not at all Useful (0)**			**AE Weighted Average**	**FM Weighted Average**	**Total Weighted Average**
	AE	**FM**	**All**	**AE**	**FM**	**All**	**AE**	**FM**	**All**	**AE**	**FM**	**All**			
Security (Requirements, procedures, etc.)	50%	59%	56%	30%	29%	28%	20%	12%	16%	0%	0%	0%	2.3	2.47	2.41
Health and Safety (Requirements, procedures, etc.	50%	82%	66%	50%	18%	34%	0%	0	0%	0%	0%	0%	2.5	2.82	2.66
Sustainability (Requirements, procedures, etc.)	65%	35%	56%	30%	59%	41%	5%	6%	3%	0%	0%	0%	2.6	2.29	2.53
Emergency Preparedness/Resiliency (Requirements, procedures, etc.)	40%	65%	50%	45%	29%	41%	15%	6%	9%	0%	0%	0%	2.25	2.59	2.41
Codes and Regulations (Local codes, regulations, requirements, etc.)	80%	59%	69%	10%	29%	22%	10%	12%	9%	0%	0%	0%	2.7	2.47	2.59
Additional written comments:	**AE:** **FM:** In the areas of codes and regs: when following a code will violate any of these 5 categories, a best practice solution must be sought through an appeal process.														

Q7: Additional comments

Question 7: Do you have any other ideas for additional FM/O knowledge classification categories that you can add or would like to share?	
Answered	**3**
Skipped	**31**
AE (2 – 5 years of experience)	Scheduling, of maintenance and building use schedules. Perhaps something on utilities or plug loads that would help with energy simulations and actual occupant behaviour. Maybe each subsection above can start with a summary of lessons learned. This almost feels like it could be a framework for POE too.
FM (10 – 20 years of experience)	Subcategories that may apply to multiple categories: Scalability - I want systems and components installed that can be built up over time or scaled back without significant impact. Redundancy - This relates to utilities, critical equipment, or critical systems that can have serious impacts on business operations if they fail. FM Staff Training - Vendor training is valuable for operations staff on new equipment/systems. This adds cost but also adds to existing FM/O capabilities. Emerging Technologies like IoT/AI/Optimization - These may provide options for diagnostics, analytics, and system integrations for lighting, BAS, mesh networks, wayfinding, energy conservation, etc. It is extremely difficult to incorporate if it is not included in the design phase. Equipment Removal/Installation - Space, adjacencies, support equipment, and clashes related to removing motors, chillers, coils, or similar challenging equipment at the end of its useful life. This may include adding beams and hoists, removeable panels, or wide corridors in the design phase. Cascade effect - e.g., Energy conservation measures that optimize energy use, but also extend filter life or equipment life. e.g., Using high efficiency freezers, which reduces electrical infrastructure demand and equipment requirements, reduces building heat load and increases HVAC life. e.g., Purchasing the "energy efficient" model that ends up significantly increasing production.
FM (More than 20 years of experience)	Under Energy and Utilities: I would like to see energy forecasting to predict future costs associated with decreasing supplies of fossil fuels vs. energy platforms that can be provided through more sustainable means.

Appendix J: Additional Diagrams

Thesis Decision Flow Diagram



DDSS – Decision Model IDEF0 Diagram

Using an IDEF0 modelling methodology (Figure J.), the proposed DDSS – Decision Model and subsystem DDSTs is conceptually diagrammed below (FigureFigure J., Figure J., and Figure J.).

IDEF0 diagrams are often used to model decisions, actions, and activities of an organisation or system. For this reason, they are used to model the systems proposed in the presented DDSTs.

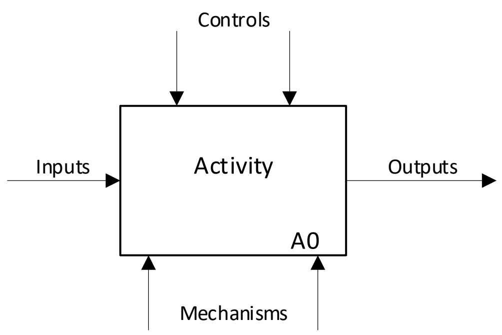


Figure J.1: IDEF0 modelling diagram key

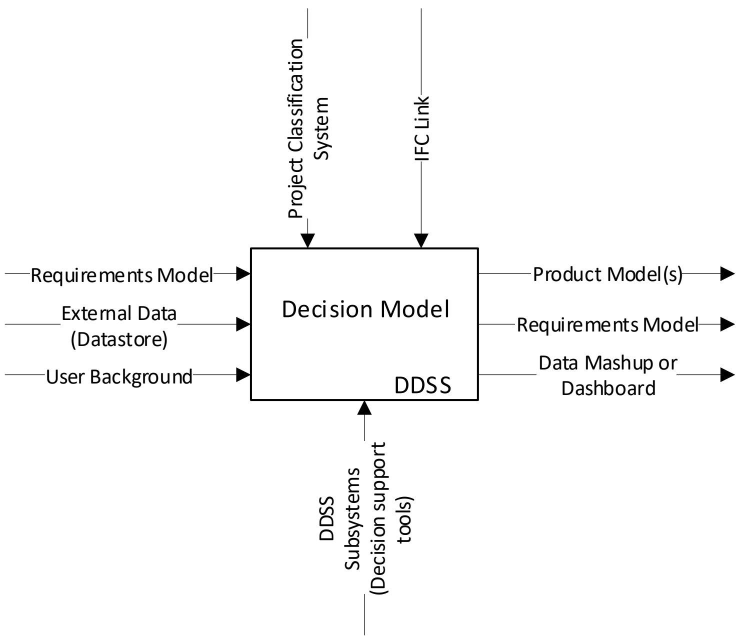


Figure J.2: DDSS – Decision model conceptual diagram

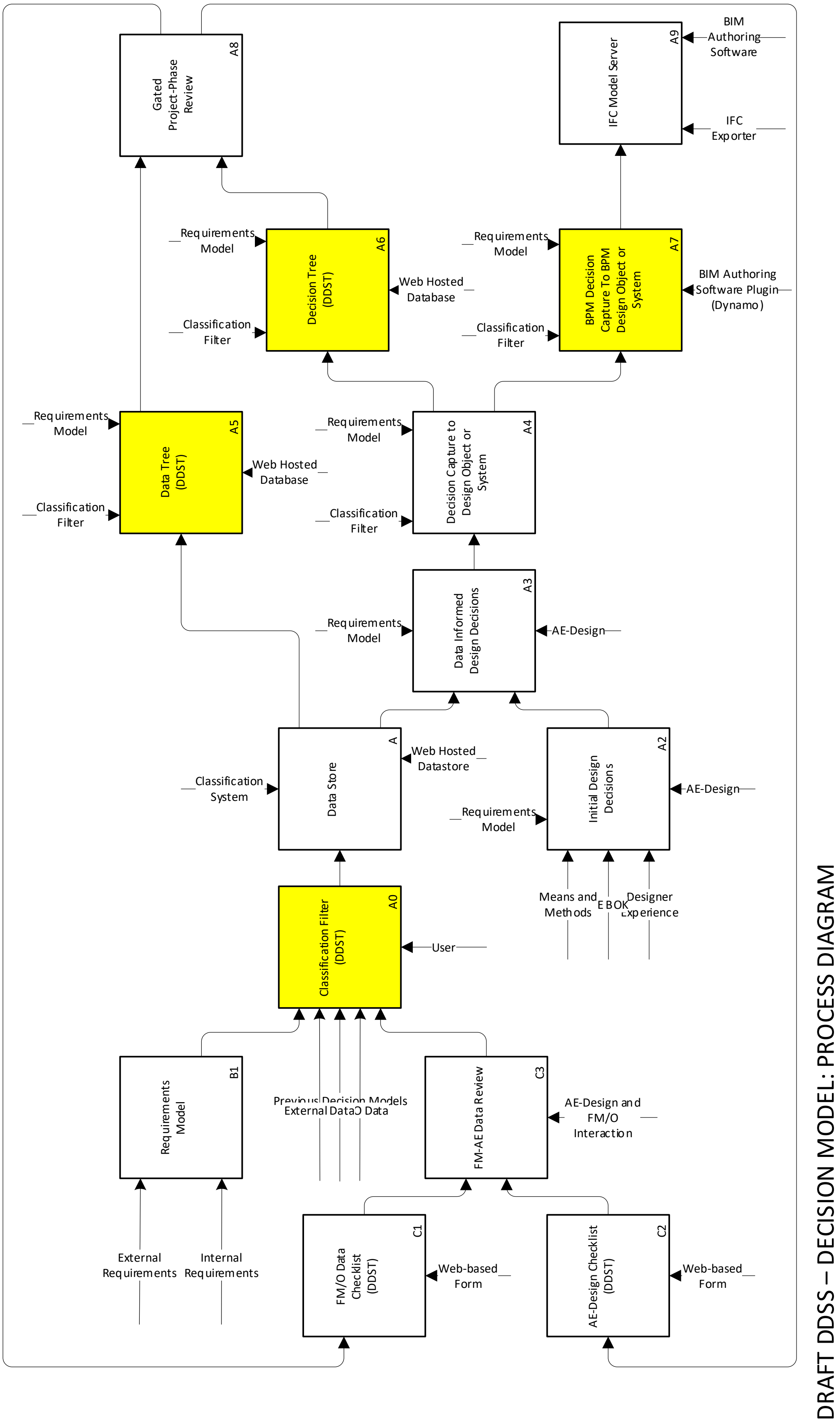


Figure J.3: Draft DDSS – Decision model process diagram

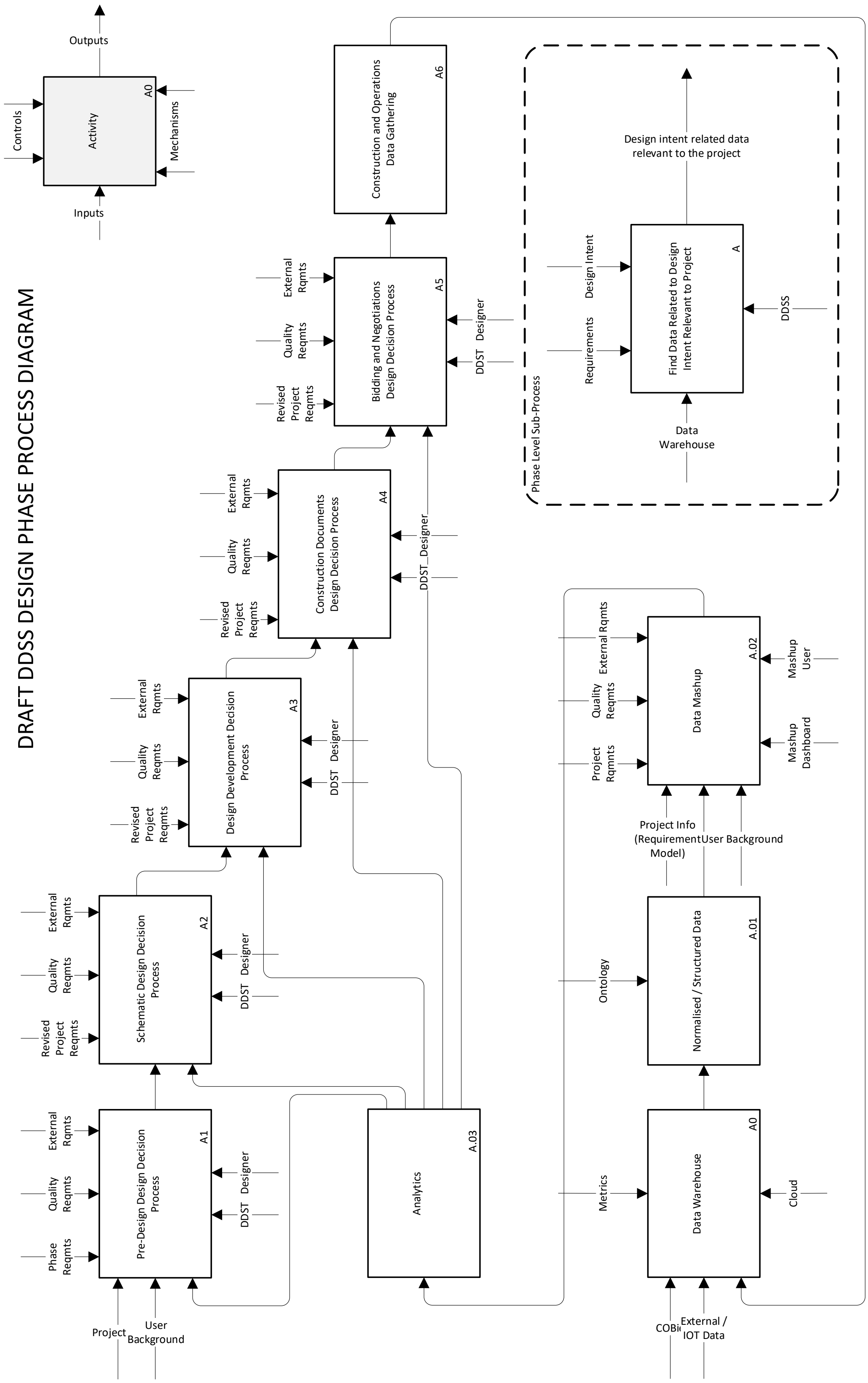


Figure J.4: Draft DDSS – Design phase process diagram