SCHOOL OF ARCHITECTURE

DEVELOPMENT OF A BUILDING INFORMATION MODELLING ASSET (BIMASSET) VALUE REALISATION MODEL

THESIS SUBMITTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE UNIVERSITY OF LIVERPOOL FOR THE DEGREE OF DOCTOR IN PHILOSOPHY

BY

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ABSTRACT

Building Information Modelling (BIM) is defined as a set of interacting processes, people and technologies that produce a methodology to digitally manage the data of a building, its performance, planning, construction, and later its operation. Although the business value of BIM has been observed during the design and construction processes, research efforts made towards documenting BIM business value when considering an asset's lifecycle are insufficient. This PhD study is based on a three-part rationale: the lack of perceived business value of BIM; weakness in BIM business value measurement techniques; and barriers of BIM implementation in the lifecycle of assets. The aim of this research is to extend the knowledge base in relation to BIM business value realisation and BIM adoption in Asset Management (AM) by developing a model that will help to guide asset owners in realising business value of BIM implementation in an AM system throughout the lifecycle of built assets. Furthermore, the scope of the study is limited to the following: client as an asset owner; asset operations in relation to AM lifecycle; and BIM implementation during asset operations.

The BIMAsset Value Realisation Model (BIMAsset VRM) is developed abductively from five sequential studies (Chapters 4-8). The BIMAsset VRM consists of six constituent elements; Influencers, Input, Output, Drivers (tangible and intangible value), Core and Business Value Realisation Dimension. Data obtained for this study is qualitative. Semi-structured interviews are used to collect data from 16 participants in 18 interviews in 6 case studies. Furthermore, documented data is sourced from these case studies in order to add depth to the study data. Data is collected in the UK, Finland, Denmark and the USA. These cases represent retail, government, health, education and consultant perspectives in AM. Data collected were analysed using mixed methods. Thematic analysis, content analysis, theoretical saturation and descriptive statistics are utilised in analysing and presenting the results of this study. The study utilised a six-member expert panel in the form of a focus group to validate the BIMAsset VRM. It is validated through expert opinion against pre-determined criteria of fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency. The results of the focus group show that there is a majority opinion that the BIMAsset VRM satisfies the above validation criteria. Furthermore, in the data analysis, there is a majority opinion that the BAMM satisfies the above validation criteria.

The study led to the following findings: (a) The study reveals that operational information requirements are strongly related to business needs and that there cannot be a rigid requirement list for all clients. (b) The study identifies that in order to successfully integrate BIM-AM systems, the asset owner should consider the following; the development for a clear strategy prior to adoption; connecting the strategy to the business goals; the discovery of organisational information needs for the development of Information Requirement templates. (c) The study establishes that there is real value to be derived by the asset owner from the effective management of asset information and there are six typologies of BIM business value that can be derived in AM; management, commerce, efficiency, industry, user and technology value. (d) The study identifies BIM strategy, contract management, lifecycle management, maintenance

management, work-order management and value realisation management as activity systems that drive BIM business value in AM. (e) The study has discovered that the capability of asset owners to derive business value of BIM in AM has implementation and maturity implications. (f) The study suggests that intangible value can be tracked and measured through the activity of business value linkage using concept maps. (g) The study posits that the entire process of BIM business value realisation management is about driving change, measuring outcomes and continuous improvement of activity systems that drive value so as to validate predicted the desirable outcomes, discover the unpredicted desirable outcome, and eliminate both the predicted and unpredicted undesirable outcomes within the BIM-based AM system.

The main scientific contribution of the study is the BIMAsset VRM which covers: (a) information requirement strategies; (b) BIM-AM systems integration techniques; (c) BIM business value realisation theory; (d) BIM-based information content management tools and techniques; (e) activity systems that drive BIM business value in AM; and (f) techniques for tracking and measuring tangible and intangible value in BIM-based processes. Similarly, the main practical contribution of this study is the deployment of BIMAsset VRM and BIMAsset Maturity Model (BAMM) in the form of a guide in an owner-operator organisation. The study discusses in great detail how an asset manager can plan, manage and implement the six dimensions of BIMAsset VRM in asset operations. Also, it presents a guide for tracking and measuring tangible and intangible BIM business value. These aspects ensure that the PhD thesis extends the current knowledge base and provides a cradle-to-grave approach to addressing the phenomenon of BIM business value realisation in an AM system during asset operations.

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DECLARATION

This thesis is presented as an original contribution based on a Doctorate of Philosophy research at University of Liverpool, Liverpool, United Kingdom and has not been previously submitted to this or any other institution for the award of a degree or any other qualification under my name or that of any other individual. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person except where due reference is made.

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LIST OF ABBREVIATIONS

AEC	-	Architecture, Engineering and Construction
AI	-	Artificial Intelligence
AIDC	-	Automated Identification and Data Capture
AIR	-	Asset Information Requirements
AIM	-	Asset Information Model
AInfM	-	Asset Information Management
AIR	-	Asset Information Requirements
AM	-	Asset Management
API	-	Application Programming Interfaces
AR	-	Augmented Reality
BAMM	-	BIMAsset Maturity Model
BEP	-	BIM Execution Plan
BIM	-	Building Information Modelling
BIMMI	-	BIM Maturity Index
BIM IP	-	BIM Implementation Plan
BIMAsset VRM	-	BIMAsset Value Realisation Model
BIM VRP	-	BIM Value Realisation Plan
BMS	-	Building Management Systems
BSC	-	Balanced Score Card
BSI	-	British Standards Institute
BVR	-	Business Value Realisation
CAD	-	Computer Aided Design
CAFM	-	Computer Aided Facilities Management
CAMS	-	Computerised Asset Management Software
CIC	-	Construction Industry Council
CDE	-	Common Data Environment
CMM	-	Capability Maturity Model
CMMS	-	Computer Maintenance Management System
COBie	-	Construction Operations Building Information Exchange
COINS	-	Constructive Objects and the INtegration of processes and Systems
CIFE	-	Center for Integrated Facility Engineering
CO_2	-	Carbon Dioxide
CSCM	-	Construction Supply Chain Management
DMS	-	Document Management Systems
DT	-	Digital Twin
DTI	-	Digital Twin Instance
DTP	-	Digital Twin Prototype

EAMS	-	Enterprise Asset Management Systems
EIR	-	Employer's Information Requirements
EMS	-	Energy Management System
FM	-	Facility Management
GDP	-	Gross Domestic Product
GSL	-	Government Soft Landings
HVAC	-	Heating, Ventilation, and Air Conditioning
ICT	-	Information Communications and Technology
IFC	-	Industry Foundation Classes
IoT	-	Internet of Things
IPD	-	Integrated Product Delivery
IT	-	Information Technology
I-CMM	-	Innovation Capability Maturity Model
IS	-	Information Systems
IRR	-	Internal Rate of Return
IWMS	-	Integrated Workspace Management System
KPIs	-	Key Performance Indicators
LOI	-	Level of Information
LOD	-	Level of Detail
MARR	-	Minimum Acceptable Rate of Return
MEP	-	Mechanical, Electrical and Plumbing
MIDP	-	Master Information Delivery Plan
mm	-	Millimetre
MTBF	-	Mean Time Between Failures
MTR	-	Mean Time to Repair
MTTR	-	Mean Time to Recovery
MVD	-	Model View Definition
m2	-	Square Metre
NBS	-	National Building Specification
NIBS	-	National Institute of Building Sciences
NDA	-	Non-Disclosure Agreements
NPV	-	Net Present Value
OIR	-	Organisational Information Requirements
PAMS	-	Plant Asset Management Systems
PIM	-	Project Information Model
PIP	-	Project Implementation Plan
PLQ	-	Plain Language Questions
PRQ	-	Primary Research Question
PMS	-	Property Management System
$(PM)^2$	-	Project Management Process Maturity

P3M3	-	Portfolio Programme and Project Management Maturity Model
PV	-	Present Value
RACI	-	Responsible Accountable Consulted Informed
RBV	-	Resource-Based View
ROI	-	Return on Investment
SIR	-	Savings to Investment Ratio
SLA	-	Service-Level Agreement
SPICE	-	Structured Process Improvement for Construction Enterprises
SRQ	-	Secondary Research Question
TIDP	-	Task Information Delivery Plan
VR	-	Virtual Reality

LIST OF PUBLICATIONS

SUMMARY OF ALL PUBLICATIONS				
TITLE: DEVELOPMENT OF A BIMASSET VALUE REALISATION MODEL				
S/No	PAPER DESCRIPTION	THEME	PUBLISHER	STATUS
1	Journal Article	BIM-Based Operational Information Requirements for Asset Owners	Architectural, Engineering and Design Management (AEDM) Journal	Published 04/01/2020 https://doi.org/10.1080/17452007.2019.1706439
2	Journal Article	Business Value of Integrated BIM -Based Asset Management	Engineering, Construction and Architectural Management (ECAM) Journal	Published 22/03/2019 https://doi.org/10.1108/ECAM-03-2018-0105
3	Journal Article	BIM Business Value Generation Theory: A Grounded Theory Approach	Journal of Information Technology in Construction	Published 15/09/2019 https://www.itcon.org/paper/2019/21
4	Journal Article	BIM Business Value for Asset Owners Through Effective Asset Information Management	Facilities	Published 25/09/2019 https://doi.org/10.1108/F-03-2019-0036
5	Journal Article	BIM Business Value for Asset Owners: A Cross Case Analysis	Journal of Facilities Management	Manuscript Under Review as of 02/10/2019
6	Journal Article	Challenges of Realising BIM Business Value in Asset Management	International Journal of Building Pathology and Adaptation	Published 20/03/2020 https://doi.org/10.1108/IJBPA-10-2019-0090.
7	Journal Article	BIMAsset Value Realisation Model: A Guide for Asset Managers	Journal of Information Technology in Construction	Manuscript Under Review as of 02/05/2020
8	Conference Paper (Peer Reviewed)	Building Information Modelling (BIM) Value Realisation Framework for Asset Owners	European Conference on Product and Process Modelling (ECPPM 2018)	Published 03/09/2018 https://doi.org/10.1201/9780429506215
9	Conference Paper (Peer Reviewed)	Development of a BIMAsset Maturity Model	36th CIB W78 2019 Conference, ICT in Design, Construction and Management in Architecture, Engineering, Construction and Operations (AECO)	Published as of 18/09/2019. ISBN: 9781861354860

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 RESEARCH BACKGROUND

Building Information Modelling (BIM) refers to a set of interacting processes, people and technologies that produce a methodology to digitally manage the data of a building, its performance, planning, construction, and later its operation (Succar, 2009; Eastman *et al.*, 2011). Furthermore, the study views BIM from the perspective of Building Information Management, where all relevant information is integrated or linked within one or more consistent datasets in the lifecycle management of built assets (Parsanezhad and Dimyadi, 2014). This is advocated as the panacea to the long-standing issues of the Architecture, Engineering and Construction (AEC) industry through the effective generation and management of information throughout an asset's lifecycle (Eastman *et al.*, 2011). Traditionally, the AEC industry is characterised with fragmentation, poor performance, low productivity, limited innovation and lowest-cost business models (Latham, 1994; Egan, 2008; Wolstenhome, 2009; Government Construction Strategy 2011-2015, 2011; Construction 2025, 2013; Government Construction Strategy 2016-2020, 2016). Recent evidence suggests that the use of data-centric models on universal interoperable platforms is widely seen as the mechanism to enhance collaboration, asset delivery, improve performance, and deliver value for money for clients in the AEC of the industry (Howard and Björk, 2008; Sacks *et al.*, 2010; Pniewski, 2011; Ayyaz, Emmitt and Ruikar, 2012; Tauriainen *et al.*, 2016; Dixit *et al.*, 2019). As a result, clients are progressively adopting BIM because it is seen to enhance coordination, cut waste, improve quality and provide more accurate information, thereby improving decision-making in the long-run (Watson, 2010). Similarly, various National Strategies have keyed into the digitalisation initiatives due to the economic potential of BIM adoption in the AEC industry (Kassem, Succar and Dawood, 2013). However, this paradigm shift will bring about disruptions to business processes (Eastman *et al.*, 2011; Jupp and Awad, 2017). As a result, there is a need for a socio-technical approach to understanding this phenomenon in order to effectively manage this change with the aim of realising the value of BIM-based investments.

Although the business value of BIM has been observed during the design and construction processes through effective management of construction activities, research efforts made towards documenting BIM business value when considering an asset's lifecycle are insufficient (Barlish and Sullivan, 2012; Love *et al.*, 2014; Kiviniemi and Codinhoto, 2014; Krämer and Besenyoi, 2018; Dixit *et al.*, 2019). Furthermore, research has shown that clients followed by facility managers would benefit most from BIM implementation (Eadie *et al.*, 2013). BIM is a management methodology used to enhance the productivity and performance of the conception, design, construction, operation and maintenance of assets throughout their lifecycle (Love *et al.*, 2013; McArthur, 2015). Several authors speculate that the business value of adopting BIM for clients will be man-power savings, cost reduction, improved indoor conditions, greater data accuracy, better space optimisation, enhanced regulatory compliance, improved inventory management and advanced configuration management (Eastman *et al.*, 2011; Becerik-Gerber *et al.*, 2012; Patrick, Munir and Jeffrey, 2012; Teicholz, 2013; Love *et al.*, 2014; Kiviniemi and Codinhoto, 2014).

In spite of all of these findings, the utilisation of BIM in the operations and use phase is lagging behind compared to the design and construction stages (Akcamete, Akinci and Garrett, 2011; Becerik-Gerber *et al.*, 2012; Love *et al.*, 2013; Kiviniemi and Codinhoto, 2014). Therefore, in order to increase adoption, there is a need to improve the understanding of clients on the economic value of BIM, the practical skills on how to utilise BIM, and the organisational prerequisites and techniques of how to create value using BIM (Vass and Karrbom Gustavsson, 2014b). Without this understanding, clients will find it difficult to achieve the desired value from BIM adoption. Consequently, this background sets the scene of this research, which is the investigation of BIM business value in Asset Management (AM).

1.2 RESEARCH SCOPE

The scope of this research study focuses on the operations and use phase of BIM implementation in the lifecycle of asset development, since the research aims to develop a model for realising BIM business value for clients. In the operations and use phase of built assets, the client can be viewed from three different perspectives, and they are; Asset Operator/ End-User, Facility Manager/

Maintainer and Asset Manager/ Asset Owner (IAM, 2012). With that said, this study focuses on business value realisation from the perspective of the client as an Asset Owner or Asset Manager. An asset owner is defined as a stakeholder that owns and operates their built assets. Similarly, asset managers are the professionals responsible for the specific task of optimising asset utilisation, increasing output, lengthening asset lifespan and increasing lifecycle value, while simultaneously minimising costs in owner-operator organisations. On the other hand, the lifecycle of BIM adoption can be studied from the following phases, and they are; Feasibility/Proposal, Development, Implementation and Operations (Willcocks and Lester, 1996). In view of this, this research focuses on BIM adoption from the Operations Phase. Finally, AM scope of application can be viewed from the following perspectives, and they are; Acquisition, Commissioning, Operation and Disposal (Davis, 2012). On this premise, this study focuses on the Asset Operations phase. The overall research scope is shown in Figure 1.1:

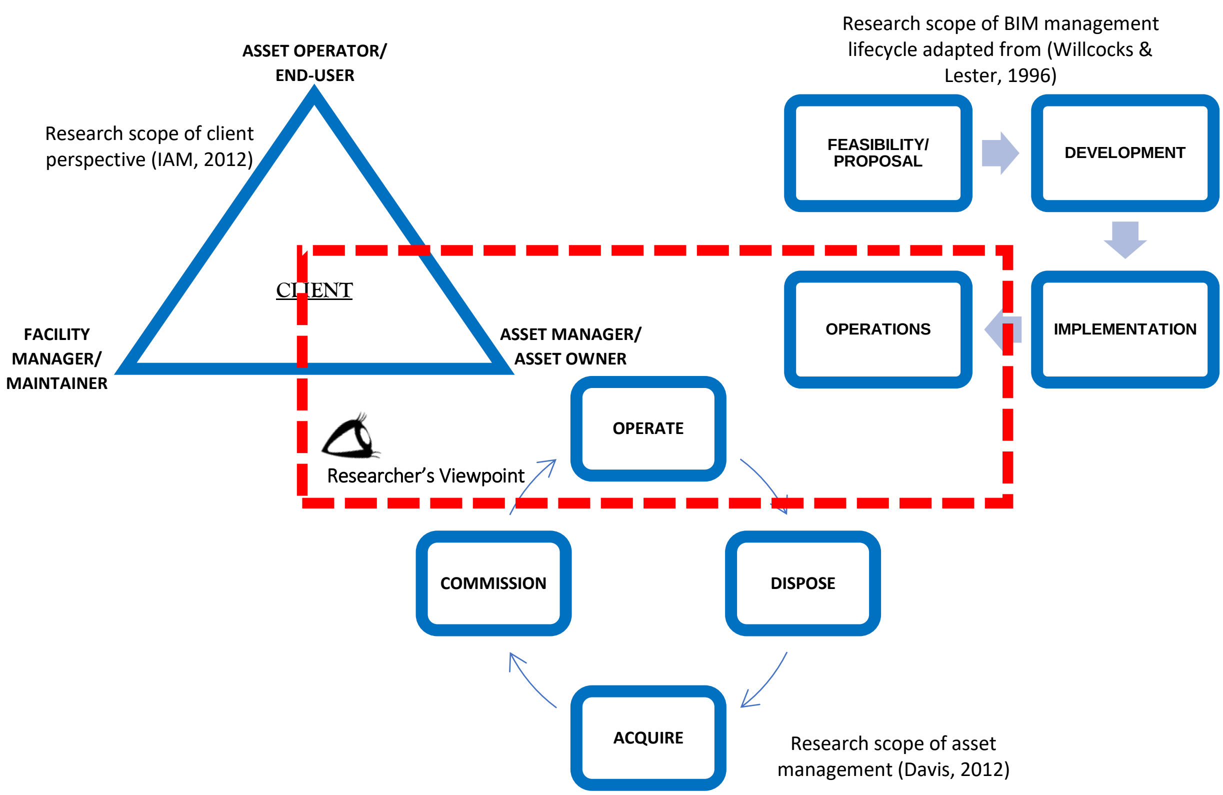


Figure 1.1: Research Scope

Furthermore, the scope of study from the AM perspective covers lifecycle management of assets in: (a) asset owners' BIM requirements through the asset's lifecycle; (b) AM system characteristics; (c) properties of asset information management systems; and (d) nature of AM activity systems. Similarly, from the BIM perspective, the study covers: (a) BIM business value for asset owners; (b) business value realisation of BIM implementation in asset operations; (c) value of information; (d) BIM maturity in relation to BIM business value; and (e) challenges of BIM business value realisation in asset operations.

1.3 GENERAL DEFINITIONS AND ASSUMPTIONS

This section presents the general definitions of the BIM terminologies used throughout the thesis:

- AM – This is a set of '*systematic and coordinated activities and practices through which an organisation optimally manages its assets, and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving its organisational strategic plan*' (BSI, 2008).
- Activity Systems – These are defined as the key AM business processes that drive business value for the asset owner.
- Asset Information Management (AInfM) – This refers to a set of integrated processes, techniques and technologies involved in collecting, organising, storing, controlling, analysing securing, sharing and reporting asset information across various sets of information models, in one database or across many databases, from handover to the disposal of a facility.
- BIM – This refers to a set of interacting processes, people and technologies that produce a methodology to digitally manage the data of a building, its performance, planning, construction, and later its operation (Succar, 2009; Eastman *et al.*, 2011). Furthermore, the study views BIM from the perspective of Building Information Management, where all

relevant information is integrated or linked within one or more consistent datasets in the lifecycle management of built assets (Parsanezhad and Dimyadi, 2014).

- BIM in AM – This refers to the utilisation of BIM tools as well as the coordinated set of activities undertaken by asset managers in order to realise the lifecycle value from assets in the delivery of business objectives (IAM, 2012).
- BIM-based process – This refers to an activity or a set of activities that rely on the use of intelligent data generated by a BIM system together with other Digital Information Technologies (DIT) to be able to conduct critical asset assessment that informs contract management, lifecycle management, maintenance management, work-order management, value realisation management or other use in order to achieve business objectives. However, the sophistication of BIM-based processes within organisations may vary due to organisational capability and maturity factors.
- BIM as an Innovation – BIM in this study is considered as an innovation because it is a whole new approach to practice and advancing the profession which requires the implementation of new policies, contracts, and relationships amongst project stakeholders (Aranda-Mena *et al.*, 2009; Eastman *et al.*, 2011). Furthermore, an innovation refers to '*the act or process of introducing new ideas, devices, or methods*' (Alreshidi, Mourshed and Rezgui, 2017).
- BIM as an IT/IS based methodology – BIM in this study is considered as an Information Technology (IT)/ Information Systems (IS) based methodology because it relies on digital tools for the delivery of digital machine-readable documentation about a building throughout its lifecycle (Eastman *et al.*, 2011).
- Business Needs: Business needs are referred to as requirements (management and operational) that drive organisational processes in order to achieve business objectives. In this context, business needs refer to AM requirements that facilitate the utilisation of reliable data provided by BIM-based processes in order for an asset owner to achieve business objectives.
- Efficient and Effective Execution of AM Tasks – This refers to having processes that support the appropriate management of resources including having the required information, at

the right time, in the right place, and in the right format for asset managers to achieve business objectives.

- Effective Management of Information – This refers to having organisational processes that support good management of information and to provide data that is comprehensive, accurate and immediately accessible to enable asset manager to make decisions faster and more accurately leading to lower maintenance costs (Lin, Gao and Koronios, 2008).
- Notion of Value – In this study, value refers to a service or outcome that is of economic benefit to an asset owner (Weigand *et al.*, 2006). This may be tangible or intangible value. An example of tangible value may be cost savings, whereas intangible value may be improved information delivery. Essentially, the notion of value in this research is economic.
- Operational Information Requirements – This refers to vital organisational requirements, which relate to AM business needs and processes, such that when utilised, it results in an immediate impact on BIM business value realisation for the asset owner.
- Thesis Audience: The targeted audience of this study is asset owners that own and operate their built assets. These are asset owners or asset managers who are responsible for optimising asset utilisation, increasing output, lengthening asset lifespan and increasing lifecycle value, while simultaneously minimising costs through BIM-based processes.

1.4 RESEARCH JUSTIFICATION

Asset owners are looking at ways to manage funds more efficiently, especially as they anticipate that collaborative working relationships brought about by BIM will be more productive, cost-effective, guarantee value for money and provide more information than present conventional methods (Cabinet Office, 2016). Therefore, the level of asset owner confidence in the business value of BIM is crucial to the measure of BIM adoption in the operations and use phase (Patrick, Munir and Jeffrey, 2012). However, there have been limited studies on the business value of BIM for the asset owner because of specific aspects that are strategic in nature which are not easily identifiable early in the BIM process (Hitt, Wu and Zhou, 2002; Grilo, Zutshi and Goncalves, 2011; Ayyaz, Emmitt and Ruikar, 2012; Marasini and Patlakas, 2012; Mirarchi et al., 2018). It is fair to say that most asset owners that are early adopters of BIM have mostly derived business value from the design and construction stage rather than the operation and use stage (Kiviniemi and Codinhoto, 2014).

Ashurst, Doherty and Peppard (2008) reason that asset owners need to develop a system that enables them to realise business value from their investments so as to enable them to have a more competitive advantage. Similarly, Patrick, Munir and Jeffrey (2012) highlight the need for further research on the confidence level of asset owners in relation to the impact of BIM on their built assets in order to derive value from BIM implementation in asset operations. The necessity for investigating BIM business value realisation management for asset owners during asset operations cannot be over-emphasised. This is because the total lifecycle of a project is three times higher than construction costs and five to seven times higher than the initial investment costs (Cabinet Office, 2012; Lee, An and Yu, 2012; Kelly *et al.*, 2013; Love *et al.*, 2013; Korpela *et al.*, 2015). BIM implementation in the operations and use phase has been riddled with management problems that have hindered the ability of asset owners to realise value from BIM-based investments (Love *et al.,* 2013; Codinhoto and Kiviniemi, 2014; Jupp and Awad, 2017; Pishdad-Bozorgi *et al.*, 2018). From the above assertions, it is clear that the phenomenon of BIM business value is poorly understood. To explore the problem further, the study identifies: (a) Clients' perceived lack of business value of BIM; (b) Existing barriers to BIM implementation in AM; and (c) Weakness in BIM business value measurement techniques; as aspects that result in the lack of understanding of the phenomenon (Lin and Pervan, 2003; Becerik-Gerber *et al.*, 2012; Love *et al.*, 2013; Vass and Karrbom Gustavsson, 2014b).

Therefore, this study seeks to address the aforementioned knowledge gaps by documenting the extent at which BIM can improve the value of built assets including the business value that can be realised from BIM implementation in the lifecycle of assets from the perspective of the client as an Asset Owner. Consequently, the research rationale for investigating the phenomenon of BIM business value in AM in this section and following sub-sections leads to the theoretical point of departure of this study.

1.4.1 CLIENTS LACK PERCEIVED BUSINESS VALUE OF BIM

Many asset owners are still uncertain about the business value of implementing BIM in AM, and for this reason, they mostly deploy BIM methodologies in design and construction phases (Akcamete, Akinci and Garrett, 2011; Arayici, Onyenobi and Egbu, 2012; Love *et al.*, 2013). As a consequence, the practical utilisation of BIM in asset operations is still rare (Eadie *et al.*, 2013; Love *et al.*, 2013; Codinhoto and Kiviniemi, 2014; Love *et al.*, 2014; Krämer and Besenyoi, 2018). Although asset owners are presumed to benefit most from BIM implementation, lack of focus in studying the impact of BIM in the operations and use phase has led to significant unrealised business value (Eadie *et al.*, 2013). Overall, BIM business value in AM are yet to be clarified, documented and explained for asset owners through real-life projects (Arayici, Onyenobi and Egbu, 2012). Similarly, there are limited studies that centre on generalising or quantifying the operational business value of BIM in asset operations (Love *et al.*, 2013; Pishdad-Bozorgi *et al.*, 2018). Considering the lack of awareness in the potential business value of BIM implementation in AM, further research is required to properly define guidelines for the level of integration, BIM deliverables and protocols in asset operations (Kiviniemi and Codinhoto, 2014). Also, there is a need to substantiate further the potential business value of BIM utilisation in encapsulating data for asset operations through the understanding of technical and administrative information workflows (Pärn, Edwards and Sing, 2017). Research in this area is justified because an asset owner who makes the investment should understand the implications and business value to be derived from implementing BIM in order to underpin organisational strategy (Love *et al.*, 2014). Hence, the rationale for researching BIM business value in AM in this study.

1.4.2 BARRIERS OF BIM IMPLEMENTATION IN THE LIFECYCLE OF ASSETS

Most of the barriers of BIM implementation for asset owners are related to strategic management challenges in the lifecycle management of assets (Love *et al.*, 2013). These management challenges require changes in business processes and the development of new roles to achieve the desired business value (Ayyaz, Emmitt and Ruikar, 2012). In an effort to address these barriers, Jupp and Awad (2017) suggest that asset owners should adjust their perspectives to technological transformation, organisational transformation and change management strategies in order to manage the organisational transition to BIM-based processes successfully. Similarly, Kiviniemi and Codinhoto (2014) suggest technology-related challenges associated with BIM implementation in asset operations can be overcome, but the organisation needs to be aware of its inefficiencies in the first place before they can be addressed.

Another challenge that asset owners face is the definition of information required from the building information model and identification of who is responsible for providing such information for the lifecycle management of assets (Ashworth, Tucker and Druhmann, 2016; Cavka, Staub-French and Poirier, 2017). This is because owner information requirements for BIM-based processes and business value to be derived for adopting BIM in AM are not understood by asset owners (Becerik-Gerber *et al.*, 2012; Cavka, Staub-French and Poirier, 2017). On the other hand, McArthur (2015) identifies challenges that must be overcome in the deployment of BIM for sustainable operations management; they are: (a) Identification of critical information required to inform operational decisions; (b) High level of effort to create new or modify existing building information models for the building(s); (c) Management of information transfer between real-time operations and monitoring systems and the building information model; and (d) Handling of uncertainty based on incomplete building documentation. These barriers, amongst other factors, have led to the slow adoption of BIM in the operations and use phase, and as a consequence, BIM business value for AM are not well characterised (Guillen *et al.*, 2016).

In retrospect, the AEC industry needs to overcome these barriers in order to realise the full benefits of implementing BIM in AM. As such, strategies, including tool and techniques for effectively implementing BIM in AM and the business value for asset owners, are investigated in this study. Hence, the rationale for researching BIM business value for AM in this study.

1.4.3 WEAKNESS IN BIM BUSINESS VALUE MEASUREMENT TECHNIQUES

A major factor responsible for the lack of BIM business value realisation are the weaknesses in business value measurement techniques. This is as a result of methods utilised in order to appraise business value. Typically, Return on Investment (ROI) is being used to justify investments in BIM.

This method does not accurately analyse the real cost and business value of implementing BIM (Lin and Pervan, 2003; Irani and Love, 2008). Furthermore, Love *et al.* (2013) argues that if financial techniques such as ROI are used to justify investment in BIM, then the entire process is limited to financial management. This faulty one-sided ROI perspective contributes to the problem by ignoring project-level business objectives and supply chain participants who are involved in delivering the asset (Love *et al.*, 2013). In addition, there are inconsistencies in identified ROI values for BIM because there are no set industry standards for evaluating such data (Neelamkavil and Ahamed, 2012). Ahzar *et al.* (2008), finds ROI values between 140 to 39,900%. Similarly, Giel, Issa and Olbina (2010), identified a wide range of ROI values between 16 to 1654%. This is because BIM projects like every other development, vary according to size and scope. Thus, ROI values cannot be generalised easily. Although the ROI results identified here are for the design and construction phases, the study could not find any evidence of ROI value in AM. Hence, the need to investigate BIM business value in AM.

Another complicated aspect is the perspective of identifying BIM business value. Here, researchers have struggled to identify methods of measuring the business value of IT-based investments such as BIM (Kuna, 2014). Most studies have focused on the economic value of BIM and not how business value can be developed and under what organisational conditions (Vass and Karrbom Gustavsson, 2014b). There are six reasons why BIM business value measurement is complex: (a) there is little economic evidence to justify making BIM-based investments, and asset owners cannot afford not to invest in BIM; (b) the difficulty of separating the contribution of BIM from other organisational processes and structures in order evaluate its contribution to business value; (c) lack of understanding of information requirements for BIM-based processes; (d) lack of understanding of strategies and techniques for effective BIM-based integration; (e) difficulty in measuring intangible value; and (f) lack of value realisation management programmes in owner-operator organisations (Willcocks and Lester, 1996; Lin and Pervan, 2003; Nogeste and Walker, 2005; Bakis, Kagioglou and Aouad, 2006; Becerik-Gerber *et al.*, 2012; Cavka, Staub-French and Poirier, 2017). Hence, the purpose for investigating strategies, tools and techniques for effectively tracking and measuring BIM business value in AM.

Asset owners need to assess the impact of BIM implementation on their business as well as project partners that rely on its implementation over an asset's lifecycle (Love *et al.*, 2013). In most asset development programmes, benefits are not defined because asset owners lack value delivery plans for BIM implementation and are unable to measure the value or realise business value in the long-run (Lin and Pervan, 2003; Reiss *et al.*, 2006). Certainly, the lack of value realisation management is a key factor of project failure (Bartlett, 2002). As a result, the value of BIM derived by asset owners in the operations and use phase has been marginal (Bosch, Volker and Koutamanis, 2015). More research needs to be conducted on the entire business process with the aim of achieving the desired business value of BIM in AM (Ward, Taylor and Bond, 1996; Irani, 2010; Patrick, Munir and Jeffrey, 2012; Love *et al.*, 2013; Love *et al.*, 2014; Parlikad and Jafari, 2016; Mirarchi *et al.*, 2018). Hence, the rationale for researching BIM business value in AM.

1.5 THEORETICAL POINT OF DEPARTURE

Consequently, for the purpose of addressing the identified problem, the researcher looks for further evidence in relation to the existing problem, which is the lack of BIM business value realisation in AM (Fischer, 2006). The study seeks published research work or case studies in relation to BIM, AM and value realisation management. This study aims to understand the problem and identify the status of research in the scoped domains of BIM, AM and value realisation management. After identifying the research problem, the researcher embarked on industry validation to confirm the theoretical exercise. The validation of the identified problem is carried out in the form of individual interviews and group meetings.

In view of the established research problem, the researcher reviews literature in order to identify any existing theory that may be useful in addressing the issue as identified in the problem statement (Fischer, 2006). However, throughout the literature review exercise, the study could not find any model or theory that was directly applicable to solve the identified problem in its entirety. Furthermore, the researcher reviews asset owners with business models that incorporate AM in their business activities. An organisation's business model refers to: what it creates (the product); who it serves (market or customer); what sets it apart (trade secret); what resources it depends on (factors of production); its important relationships (stakeholders); how it delivers value (supply chain); how it generates revenue (sales); and what its major costs are (liabilities) (Malone *et al.*, 2006). The researcher classifies business models that fall under the Physical Landlord or Owner-operator type as the nature of asset owners to be investigated in this study (Malone *et al.*, 2006; ONS, 2007). This is shown in Appendix E.

Against this background, this study views value as a service or outcome that is of economic benefit to an asset owner (Weigand *et al.*, 2006). This may be tangible or intangible value. Essentially, the notion of value in this research is economic. The study views BIM business value from the perspective that value is interpreted as subjective constructs that are constructed from lenses of actors through rational and economic organisational perspectives (Vass, 2014a; Vass and Karrbom Gustavsson, 2014b). Literature has shown that business value realisation is often expressed as a process-based model that can be applied in any business environment (Leyton, 1995; Mooney, Gurbaxani and Kraemer, 1995; Ward, Taylor and Bond, 1996; Sapountzis, Harris and Kagioglou, 2007; Sanchez, Mohamed and Hampson, 2016). Although some models are conceptual in nature (Melville, Kraemer and Gurbaxani, 2004; Love *et al.*, 2014), this study adopts the process-based view. Therefore, the process of value generation within the AM system needs to be investigated. It can be argued that value is not absolute in the properties of any system or product but is generated as a result of the user's experience of the system (Kujala and Väänänen-Vainio-Mattila, 2009). Hence, product properties are only indicators of value (Boztepe, 2007a). Consequently, value can be characterised as the practical or symbolic result generated through the interaction of the user and product (Boztepe, 2007b). In other words, the interaction between the asset owner and the BIM system. However, these interactions occur in every AM system that is integrated with BIM but lack the theoretical framework to articulate and define correlations with respect to business value realisation. Therefore, by focusing on the business value which the asset owner can realise from the interaction between asset managers and BIM, the research objectives can be fulfilled.

In accordance with the above assertions, Kujala and Väänänen-Vainio-Mattila (2009) present a model that characterises the relationship between the user (Asset Owner) and product (BIM) in the context of value realisation development. Here, the Asset Owners' values, needs, goals and limitations, and BIM properties are expressed as critical dependencies to the union in relation to business value realisation. Furthermore, Kujala and Väänänen-Vainio-Mattila (2009) define the two aspects that deal with what the users' (Asset Owner) expectations and what the product (BIM) offers. The researcher adapts this model (Figure 1.2) to explore how to address the phenomenon of BIM business value realisation in AM by exploring:

- How the interaction between the Asset Owners' (values, needs, goals and limitations) and BIM (properties and methodology) generate value for built assets in an asset management system?

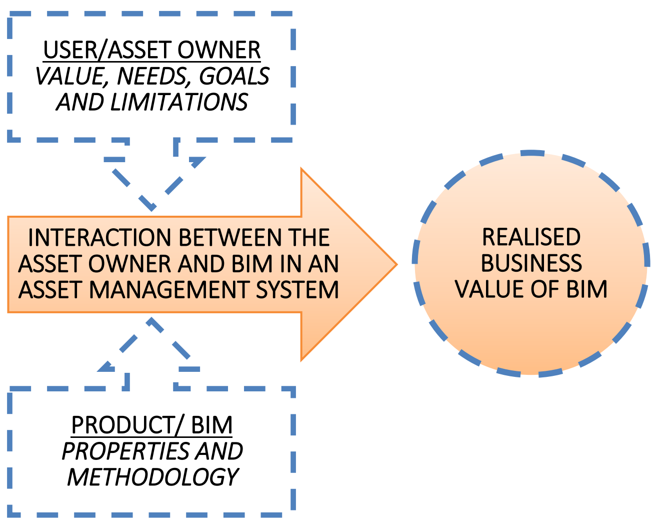


Figure 1.2: Value realisation model adapted from Kujala & Väänänen-Vainio-Mattila (2009)

Furthermore, AM in its core aims to enable organisations to generate and realise value from their assets in optimising asset performance, enhancing the quality of service and balancing risk, financial, social and environmental costs (Hastings, 2009). Given that AM is central to value generation, the adoption of the model presented by Kujala and Väänänen-Vainio-Mattila (2009), and the underlying concepts, dependencies and framework of value realisation forms a clear point of departure for this study.

This adapted model (Figure 1.2) highlights why a socio-technical approach is needed. In this study, BIM is considered as an IT/IS based technology, and its implementation has social, management and operational implications. Therefore, the study seeks to adopt a socio-technical approach which seeks to investigate the interaction between the asset owner and BIM in an AM system. It is assumed that the appropriate implementation of BIM by an asset owner would enable effective execution of AM tasks, which in turn ensure the achievement of business objectives. Consequently, the attainment of business objectives will result in an immediate impact on BIM business value realisation for the asset owner. From the findings in Section 1.4, the study outlines the following factors as topical areas that impact on the lack of BIM business value realisation by asset owners:

- The lack of clear definition of information requirements for BIM-based processes by asset owners is a major barrier to BIM implementation and subsequent value realisation (Ashworth, Tucker and Druhmann, 2016; Cavka, Staub-French and Poirier, 2017).
- The inadequate level of understanding of asset owners on the techniques for organising BIM and AM systems to work efficiently during asset operations is a significant barrier to BIM implementation and subsequent value realisation (Becerik-Gerber *et al.*, 2012; Jupp and Awad, 2017).
- The lack of awareness of tools and techniques for digitally managing asset data is a major constraint to BIM implementation and subsequent value realisation (Becerik-Gerber *et al.*, 2012; Eadie *et al.*, 2013).
- The lack of awareness by asset owners on key business processes that drive BIM business value during asset operations is a major challenge to BIM implementation and subsequent value realisation (Kiviniemi and Codinhoto, 2014).
- The insufficient understanding by asset owners of approaches, tools and techniques for evaluating BIM business value during asset operations is a primary barrier to BIM implementation and subsequent value realisation (Love *et al.*, 2013; Love *et al.*, 2014).

Consequently, the above factors that hinder BIM business value realisation are socio-technical in nature. This is because they contain aspects of technological constraints, including management and operational challenges. Therefore, it is deemed appropriate to adopt a socio-technical approach in addressing the identified research problem. The investigation of these factors is expected to guide the identification of relevant components, elements and sub-elements of the proposed value realisation model. Furthermore, the aforementioned factors guided the development of the aims and objectives of the study, which centre on the development of a BIM business value realisation model that will guide the interaction between asset owners and BIM for the purpose of BIM business value realisation. In addition, the formulation of research questions is necessary to identify aspects of the phenomena to probe as a result of the developed research objectives (Section 1.6). This section of the thesis constitutes the theoretical point of departure.

1.6 RESEARCH AIM AND OBJECTIVES

The research aims to investigate BIM business value for clients and how it can generate value for physical assets. Specifically, this study will investigate and provide a model for clients to realise the business value of BIM implementation in an asset management system in the lifecycle of assets.

The Objectives of the study are:

1. To identify the key operational information requirements in AM business processes and how they relate to BIM.
2. To investigate and identify the strategies and techniques of how asset owners can integrate BIM with AM systems and the business value to be derived from such integration.
3. To investigate how the information content collected from built assets generate business value in a BIM-based Asset Information Management (AInfM) system including key techniques of managing asset data and how that data is reported for critical decision-making.
4. To investigate, identify and evaluate activity systems that drive BIM business value in AM.
5. To investigate the techniques and strategies of measuring the business value of BIM in AM processes and how intangible value can be measured.
6. To develop a model for business value realisation of BIM implementation in the lifecycle management of assets for clients.

1.7 RESEARCH QUESTIONS

The development of a research question is necessary to express the purpose of study within the subject area (Saunders, Lewis and Thornhill, 2016). The research questions are developed based on the research objectives. These are developed in order to narrow in on the specific phenomena to be investigated. Therefore, in order to effectively achieve the research objectives, the thesis will address the following Primary Research Question (PRQ):

PRQ - How can the BIMASSET Value Realisation Model support asset managers in deriving BIM business value?

In order to answer the primary research question in a methodical manner, secondary research questions are developed. Creswell (2003) suggests that in addition to the primary research question, five to seven secondary questions are appropriate. This study formulates six Secondary Research Questions (SRQ):

SRQ-1–What are the important and common requirements for AM processes, and how do these requirements relate to BIM?

SRQ-2–What are the techniques and strategies of streamlining BIM-AM systems and what information should be captured from physical assets towards BIM-based integration?

SRQ-3–How does the information content captured from physical assets generate business value in AM, and which aspects relate to BIM?

SRQ-4–What are the vital AM business processes that drive BIM business value, and how do they relate to business process maturity?

SRQ-5–What are the techniques and strategies of measuring the business value of BIM in AM processes, and how can intangible value be linked to tangible value?

1.8 THESIS STRUCTURE

A brief description of each chapter is expressed in this section, including the progression of the thesis. The thesis consists of eleven chapters. This is shown in Figure 1.3: The following sub-sections outline the structure of the thesis:

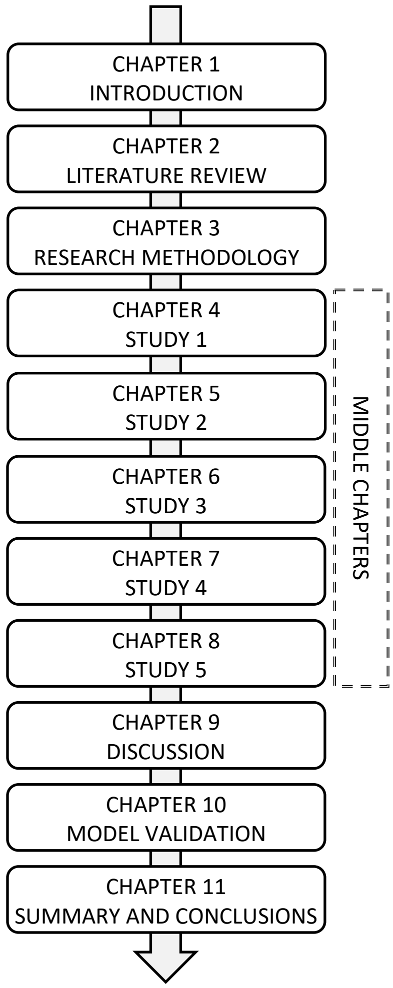


Figure 1.3: Thesis structure

1.8.1 INTRODUCTION (CHAPTER 1)

This introductory chapter presents the background of the research, statement of problem justification for study, theoretical point of departure, aims and objectives, research question and thesis structure. This chapter first gives a brief background and overview of BIM business value in AM in order to present an introduction to the subject matter and highlight the rationale for the research, including what the study intends to achieve.

1.8.2 LITERATURE REVIEW (CHAPTER 2)

In this chapter, the researcher will review relevant literature related to the area of study. The aim of this chapter is to critically analyse relevant literature as indicated by the theoretical point of departure. This chapter explores various aspects of the phenomena of BIM business value in AM in order to establish a foundation for achieving the research objectives.

1.8.3 RESEARCH METHODOLOGY (CHAPTER 3)

The third chapter is concerned with the methodology used for this study which demonstrates the philosophical stance of this study. A detailed research methodology is presented including qualitative research methods, research design, validation tools and ethical considerations.

1.8.4 MIDDLE CHAPTERS (CHAPTERS 4-8)

The fourth section comprises of five chapters which present the findings of the research. In these chapters, the study outlines more specific aspects of the research methodology adopted, articulates the rationale for data collection methods and analysis used, and reports the research findings. These chapters present the analysed data in a comprehensible format and discusses the results obtained throughout the research exercise. In these chapters, the researcher summarises the major findings of the research and concludes as appropriate. Finally, the framework is presented in Chapter 8.

1.8.5 DISCUSSION (CHAPTER 9)

This chapter discusses the results and findings of the middle chapters. It further provides justification for the selection of elements and sub-elements of the proposed model (BIMAsset Value Realisation Model).

1.8.6 MODEL VALIDATION (CHAPTER 10)

This chapter focuses on validating the outcome of the study, which is the BIMAsset VRM. It highlights the criteria for model validation, including responses of the respondents.

1.8.7 SUMMARY AND CONCLUSIONS (CHAPTER 11)

The final chapter draws upon the entire thesis, tying up the various theoretical and empirical strands in order to highlight how the aim and objectives formulated in the first chapter have been achieved. The aim of this chapter is to summarise the key contributions (theoretical and practical) of the study and give recommendations, including implications for future research. Finally, the conclusion gives a brief summary of the research process and critique of the findings.

1.9 CHAPTER SUMMARY

This chapter outlines the basis for conducting this study by exploring the background of the phenomenon of BIM business value in AM, determining the scope, justifying the research purpose, articulating the point of departure, defining the aims and objectives and formulating the research questions. These sections serve as a guide to the overall purpose of this thesis and how it is structured.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 CHAPTER INTRODUCTION

The research problem, as identified in Chapter 1 is socio-technical in nature. As such, this chapter is laid out to explore these issues. The main aim of this chapter is to explore existing literature within the domains of Asset Management (AM), Building Information Modelling (BIM) and business value realisation. The first area is the background of asset owners, where relevant types and characteristics, business models, including strategic management, are reviewed. The common challenge is that asset owners are not a homogenous group of organisations. Therefore, the typical nature of any asset owner is markedly different, and these organisational protocols make it difficult to maintain the same processes or approaches; this is particularly the case amongst organisations within the same sector. The second area of exploration, appraisal and review is AM, with a specific focus on socio-technical topical areas. The social areas of focus concern AM practices, asset register, asset hierarchy and Asset Information Management (AInfM). The technological areas of focus are AM systems, AInfM systems, including other Digital Information Technologies (DIT) that contribute to the overall objective of AM. These socio-technical issues in relation to AM are all discussed in order to develop a solid foundation to support the achievement of research objectives. The third area of focus is BIM with a specific focus on implementation and business value realisation in AM during asset operations. Therefore, the social and technological factors that impact BIM business value are explored and discussed. The social areas of focus are BIM organisational strategy, change management, stakeholder management, performance management, standards and business process maturity. The technological areas of focus are information requirements, BIM technological systems and the BIMAsset. The fourth area of search is business value realisation, where relevant literature related to BIM are explored. Therefore, the study reviews BIM value realisation management, evaluation frameworks and measurement techniques. This chapter provides the secondary data for the development of the BIMAsset Value Realisation Model (BIMAsset VRM). The literature review guided the research process in developing the interview questions where it set the area of exploration and subsequent thematic analysis in the case studies undertaken in the result chapters (4-8).

2.2 NATURE OF ASSET OWNERS AND BUSINESS MODELS

Firstly, there is a need to define further the scope of the asset owner within the context of this study. Previously, the study defines the client as an asset owner or owner-operator. However, Masterman (2002) suggests two client sectors, public and private, including other characterisations such as primary, secondary, experienced, and inexperienced clients or asset owners. Also, Galbraith (1995) identifies groupings for AEC industry asset owners, which are based upon organisational factors. These are classified under traditional professions, newer professions, industrial sector and average industry asset owners. However, the aforementioned factors are influencers, and as a result, asset owners acquire very distinct characteristics. Taking this into account, the study focuses on both public and private asset owners, as suggested by Masterman (2002). Furthermore, the study focuses on education, health, retail and government (mixed-use) clients. This is due to the limitation of getting respondents for the study. However, the sampled asset owners are not a homogeneous organised group of organisations, and are thus not expected to apply uniform standards (Masterman, 2002). The institutional owner such as a government ministry would generally be less responsive than the privately or publicly owned retail organisation. Similarly, education and health owners would be expected to focus on achieving business objectives that relate to the provision of nominated services to their customers.

There is a diverse range of business models and in relation to asset owners or owner-operators. Business models that cover owner-operators may include owner-occupier, rented property, real estate traders and real estate brokers. Only owner-occupiers and rented tenants are viewed as dwelling and office stock (GOV.UK, 2012). Furthermore, Malone *et al.* (2006) classified business models into 16 archetypes as shown in Figure 2.1:

Basic Business Archetypes	Type of Asset Involved			
	FINANCIAL	PHYSICAL	INTANGIBLE	HUMAN
CREATOR	Entrepreneur	Manufacturer	Inventor	Human Creator
DISTRIBUTOR	Financial Trader	Wholesaler/ Retailer	IP Trader	Human Distributor
LANDLORD	Financial Landlord	**Physical Landlord**	Intellectual Landlord	Contractor
BROKER	Financial Broker	Physical Broker	IP Broker	HR Broker

Figure 2.1: Business model archetypes (Malone *et al.*, 2006)

The study identifies the Physical Landlord (Figure 2.1) business models as the generic classification that may be applicable to owner-occupiers and real estate tenant asset owners. Also, the study views the Physical Landlord as the preferred business model for developing and applying the proposed BIMAsset Value Realisation Model (BIMAsset VRM). Furthermore, the study explores various business models in a bid to identify types of businesses that incorporate AM in their activities. The study classifies business models that fall under the Physical Landlord type into owner-operator and rented tenants (ONS, 2007). A number of owner-operator business models for asset owners are identified from the ONS (2007) classification list (Items G, H, I, K, L, P, Q, and R). These are shown in Appendix E.

In addition, Morledge and Smith (2006) assert that asset owners' characteristics and experience remains a critical factor in determining client attitude and dealings with other stakeholders in the AEC industry. Also, due to the fact that there are diverse asset owners in the AEC industry, it is worth noting that the proposed BIMAsset VRM (Chapter 8) may not cover all client requirements and values. This unique diversity within asset owners will certainly impact on information requirements, business processes, organisation values, organisational strategy and management structure. Even similar organisations performing the same business functions and competing in the same market may have different methods of performing the same task. This factor, amongst others, makes BIM adoption and subsequent value realisation a challenging task for asset owners. Hence, the need to further explore the phenomenon of BIM business value realisation within the context of asset owners or owner-operators.

2.3 STRATEGIC MANAGEMENT

The critical role for asset management is to align with and deliver the goals of an organisation's strategic plan (IAM, 2012). As such, strategic management literature needs to be investigated in this study. A strategy is referred to as the broad definition of the goals of an activity and determination of specific alternative plan of action to achieve the pre-defined goals (Omalaja and Eruola, 2011). AM suggests broader views from: tactical to strategic; isolated phased to full lifecycle; individual assets to asset systems and system of systems; and discrete processes to integrated management systems (IAM, 2012). As such, the phenomenon of BIM business value realisation in AM is strategic in nature. BIM business value realisation is the organisational approach to achieving overall business objectives and developing a suitable organisational plan of action to implement BIM and realise business value from its adoption. Therefore, strategic management refers to the organisational process of developing objectives, policies, planning and commitment of resources, including acknowledgement of constraints (Langford and Male, 2001). Strategic management concerns strategy development, implementation and evaluation. Therefore, the study suggests the same approach towards BIM business value realisation during asset operations. That is, the need for the asset owner to develop appropriate business objectives for BIM adoption, approaches for its implementation, and techniques for evaluating BIM business value. As such, the study seeks to investigate three domain areas further: AM, BIM and business value realisation.

Strategic management in the AEC industry requires unique consideration due to its personalised project-based nature. Furthermore, asset owners have unique approaches to technical, management and operational activities. As such, addressing the challenges of BIM business value realisation would require a flexible approach that would suit these various factors. As a starting point, the study looks at strategic management theories in order to further explore the research problem. There are a number of strategic management theories such as resource-based, profit-maximisation, survival-based, human resource-based and contingency theory in the normative literature. Resource-based theory is derived from the management philosophy where the competitive advantage of an organisation lies in its ability to exploit its internal strategic resources rather than the organisation's standing in the external environment (Barney, 1991). Profit maximisation theory refers to the notion by which the main objective of an organisation is to determine the price, input, and output levels that leads to the highest long-term profit (Hornby, 1995). Survival based theory refers to the notion that only the best and fittest competitors will survive including those organisations that continuously improve and adapt to the changing business environment (Freeman, 1974). Human resource-based theory is the management philosophy that highlights the importance of the people element in strategy development, motivation and cultures of organisations (Lynch, 2006). Contingency theory is an organisational theory that suggests that there is no single best approach to managing organisations, only optimal actions that are determined by the internal and external situations (Morgan, 2006). These strategic management theories shed some light on the strategic nature of the research problem. The resource-based theory implies the need for asset owners to exploit their internal resources (BIM, AM, management and operational systems). The profit maximisation highlights the need for asset owners to realise value from BIM-based processes. The survival theory infers the need for asset owners to adapt to AEC technological transformation in order to survive. Human resource-based theory highlights the need for focusing on social aspects of the organisation in developing strategies for realising BIM business value in AM. Lastly, contingency theory underscores the need to focus on the relationship between the application of technological (BIM) and management behaviours (AM) in specific situations (asset operations) during BIM business value realisation. However, more research is required in order to develop a value realisation model that would seek to assist asset owners in realising BIM business value.

2.4 ASSET MANAGEMENT (AM)

An asset is generally viewed as an economic resource owned by an individual or corporation that may be tangible or intangible (Davis, 2012). An organisation has the following types of assets;

physical, human, information, financial and intangible assets (BSI, 2008). Physical assets are items such as plant, machinery, buildings, roads, vehicles, railways, aircraft, pipes, wires, communications equipment and other infrastructure (Hastings, 2009). Human assets, also known as human capital, refer to the collective value of an organisation's intellectual competencies, knowledge, and skills. Information assets entail the provision of good quality data to implement asset management plans. Financial assets provide support for infrastructure investments, operation and maintenance. Intangible assets refer to aspects such as patents, reputation and trademarks that have significant effects on an organisation's investments, operating costs and strategies. The other types of assets support the management of physical assets (Hastings, 2009). This study focuses on physical assets and specifically built assets, including other types of assets that make it functional.

Principally, there is a need to define AM within the context of this study. PAS 55-1 (BSI, 2008) defines AM as a set of '*systematic and coordinated activities and practices through which an organisation optimally manages its assets, and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving its organisational strategic plan*'. Similarly, Schneider *et al.* (2006) define AM as *'operating a group of assets over the whole technical life-cycle, guaranteeing a suitable return while ensuring defined service and security standards'*. On the other hand, ISO 55000 (2014) defines AM as a '*coordinated activity of an organisation to realise value from assets'*. Essentially, AM is a crucial business activity that is central to the overall organisational strategy of many asset owners because it contributes considerably to their financial objectives (Hastings, 2009). Asset managers perform the difficult task of operating assets at optimal levels whilst keeping maintenance costs down. AM is an intensive process that consists of many sub-processes to manage an asset throughout its lifecycle (Ouertani, Parlikad and Mcfarlane, 2008). AM as a methodology is positioned between the technical and business fields within organisations. This is so because requisite knowledge of both technical and business, which is needed to effectively and efficiently manage the asset related needs of an asset owner (Hastings, 2009). In order to meet the organisations business objectives, AM involves: identifying what assets are needed; identifying funding requirements; acquiring assets; providing logistic and maintenance support for assets; and disposing of and renewing assets (Hastings, 2009). Furthermore, AM has the following goals; cost efficiency; capacity matching; meeting customer requirements or needs; and market leadership (Amadi-Echendu, Willett and Mathew, 2010). An organisation's AM strategy affects the profitability and operational efficiency of businesses processes.

There is a clear distinction between managing assets and AM (BuildingSMART, 2018). Managing assets refer to the day-to-day activities concerning the repair, maintenance and keeping the physical asset in good condition. Whilst AM concerns managing the services that support an asset in line with organisational objectives, needs and values. AM covers many disciplines, and they are; physical, financial, enterprise, infrastructure, strategic, property and facilities asset management (IAM, 2012). Physical asset management is the business process of managing the entire lifecycle of physical and infrastructural assets from conception to disposal. Financial asset management is the business process of managing the financial assets of an organisation, which includes investment funds and client accounts. Enterprise asset management involves the utilisation of information systems that support the business process of management of assets by an organisation. Infrastructure asset management is the multidisciplinary methodology of the effective management of public infrastructure assets. Strategic asset management involves the process of analysing asset conditions, demand, forecasts and development of asset management and replacement strategies. Property asset management involves the maximisation of property value and investment returns through the acquisition, improvement, leasing and resale of real estate properties. Facilities asset management is the business process of efficient and effective delivery of support services for the management of an organisation's assets. Against this background, this study focuses on physical asset management.

Furthermore, AM can be described as an integrated framework which enables asset owners to achieve their organisational objectives in a structured way through a combination of tools and techniques. IAM (2012) presents a conceptual model to describe the scope of AM (Figure 2.2). This model shows the groups and activities that are required within the AM discipline. The model further demonstrates that at the core of AM remains a need for effective integration of these groups in order to achieve organisational objectives.

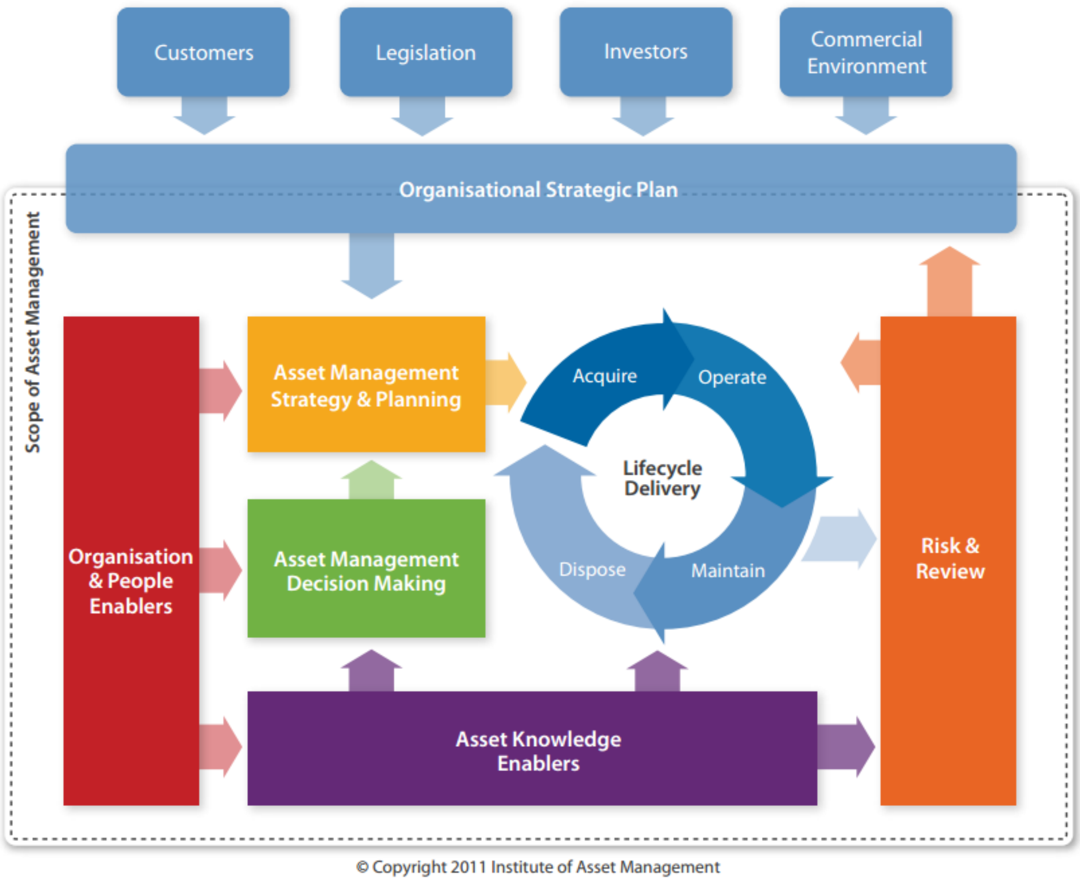


Figure 2.2: Scope of asset management (IAM, 2012)

Therefore, it is important for asset managers to ensure effective utilisation of asset information within their organisations in order to efficiently execute business processes. It is expected that the profitability of assets will increase over time through the adoption of best practices of managing and maintaining assets in optimal condition (Schneider, *et al.*, 2006). As a result of the strategic nature of physical AM which focuses on delivering value to the organisation lies the rationale for identifying the strategic business value of BIM-based processes in AM in this study (Chapters 4, 5, 6, 7 and 8).

2.4.1 ASSET MANAGEMENT SYSTEM

An AM system is a methodology that combines three elements of organisational resources; people (expertise and human resource), process (business tasks) and technology (systems) (Mehta and Reddy, 2015). An AM system supports asset planning and maintenance including other support systems such as IT, financial and legal services (Hastings, 2009). New technologies in AM support asset managers to predict events, diagnose causality and create value using historical or real-time data to reduce cost and risks of failure (Parlikad and Jafari, 2016). There are a number of technologies that help AM tasks such as Document Management Systems (DMS), Enterprise Asset Management Systems (EAMS), Computerised Maintenance Management Systems (CMMS) and Plant Asset Management Systems (PAMS) (Koronios, Lin and Gao, 2005). Furthermore, Mehta and Reddy (2015) suggest eight key drivers of an AM system, and they are: reliability; quality; increased production; man-power reduction; cost reduction; understanding customer requirements; environmental health and safety; and value creation. Similarly, PAS 55-1 (BSI, 2008) provides a requirement checklist for the establishment of an AM system that covers the definition of a clear policy, strategic approach, AM plans, operational controls and continual improvement activities (IAM, 2012). Also, an AM system should specify the competency requirements for personnel as well as other support services such as financial, legal and IT across all activities involved in AM (Hastings, 2009).

Nevertheless, the key driver of an AM system is customer demand, which is further interpreted into business objectives and business plans. An AM system aims to fulfil the customer demand by accomplishing organisational objectives through established business plans. With that said, there is a need for asset owners to align their business objectives with their AM strategy in order to have synergy between the elements of organisational resources in AM. Furthermore, good management of asset provision, responsive support services and reliable supply of resources are central for the sustainability of an AM system (Hastings, 2009). To further explain the phenomena of AM systems, IAM (2012) presents a model which explains classification and hierarchy of assets within an AM system in relation to organisational strategic goals (Figure 2.3).

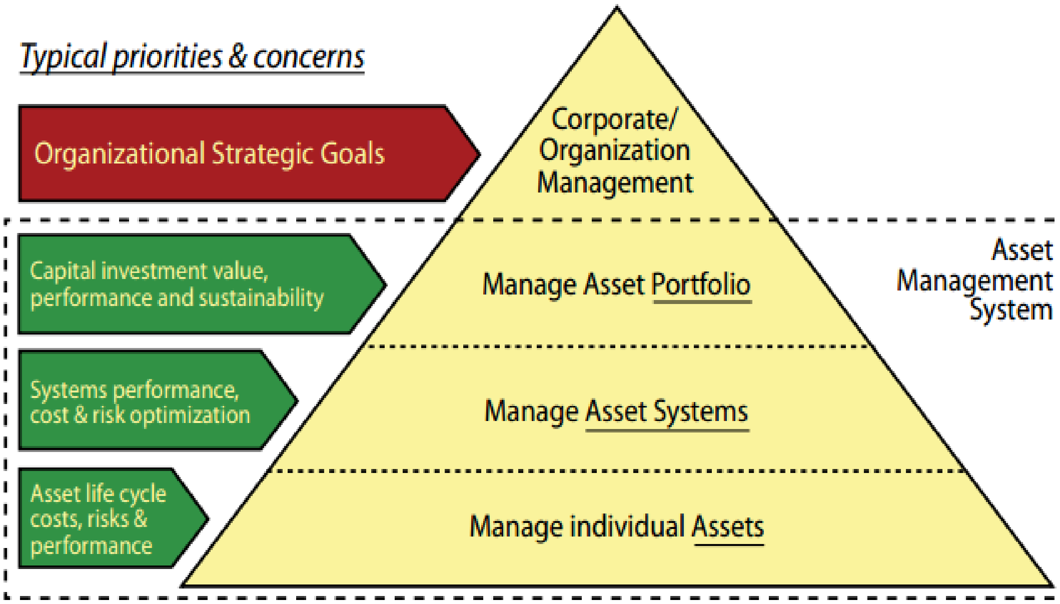


Figure 2.3: Showing asset classification in an asset management system (IAM, 2012)

On that premise, the study identifies a lack of understanding from asset owners on the impact of organisational resources on value creation, value management and value realisation. As a result, there is a need for this study to investigate AM system of asset owners that are adopters of BIM-based processes in order to explore how to effectively manage asset data in an AM system.

2.4.2 ASSET MANAGEMENT PRACTICES

The practice of AM involves the creation, acquisition, maintenance, operation, renewal, rehabilitation and disposal of assets. Generally, AM is about understanding risks and developing good business strategies through appropriate organisational processes and technological models to manage an asset (Mohseni, 2003). Progressively, asset owners are deploying AM systems to enhance overall operational efficiency through increased reliability, improved quality, manpower reduction, cost reduction, and value creation (Mehta and Reddy, 2015). Owner-operator organisations that are still reliant on highly inefficient paper-based processes which lack accurate insight into asset performance data such as real-time operating hours, asset condition, maintenance cost, asset maintenance history and inventory levels. Even if some asset owners are able to execute these tasks, it is hardly ever possible to achieve them in an efficient way. Efficient execution of AM tasks refer to having processes that support the appropriate management of resources including having the required information, at the right time, in the right place, and in the right format for asset managers to achieve business objectives. Effective AM is heavily dependent on the quality of information contained in the Asset Information Models (AIM), which can be used to simulate and predict different aspects of asset performance throughout its service life. The data from the AIM is generally used for probabilistic or deterministic approaches to modelling and to make asset predictions (Berardinell *et al.*, 2014). Similarly, BIM can support asset maintenance operations for both new and existing buildings (Patacas *et al.*, 2015). These modelling techniques help asset managers forecast the allocation of resources in order to fulfil the performance requirements of built assets.

The process of AM is dependent on the knowledge of the asset manager in relation to organisational assets. This involves a variety of factors such as current level of technology, condition, capability, deployment, limitations, business role, and the potential future developments of an organisation's assets (Hastings, 2009). In achieving that asset managers seek to establish appropriate thresholds for strategic maintenance management by applying various standard maintenance practices (Khurshid, Irfan and Labi, 2011). Asset maintenance operations involve major repairs, replacement or rehabilitation activities carried out to restore the condition of a structurally or functionally deficient asset (Berardinell *et al.*, 2014). BIM can act as a fundamental information source that could provide support to the asset owner with a wealth of asset maintenance data that will assist managers in critical decision-making (Chen *et al.*, 2018). Generally, asset maintenance activities fall into two main categories; preventive and reactive (Tsang, 1995).

2.4.2.1 PREVENTIVE MAINTENANCE

Preventive maintenance, also referred to as scheduled or planned maintenance is a proactive strategy for maintaining built or physical assets through scheduled maintenance activities at certain intervals in order to ensure the effective performance of an asset. These scheduled activities are carried out to extend the service life of an asset and to prevent its breakdown, unnecessary failure and productivity downtime. Preventive maintenance has been developed in response to the traditional maintenance approach, where assets are only fixed when they are broken (Tsang, 1995). Precautionary actions may fall under preventive, predictive, proactive and passive (Muchiri *et al.*, 2017). The benefits of this maintenance approach are better efficiency, long asset life, high safety and less downtime. Preventive maintenance extends the service life of an asset, thereby reducing the need for premature replacements or capital investments in the long-run. Another benefit of preventive maintenance is the reduction of asset downtime incidents as a result of fewer breakdowns. Preventive maintenance may help enhance the efficiency of an asset, thereby making them run more efficiently.

2.4.2.2 REACTIVE MAINTENANCE

Reactive maintenance is also referred to as corrective maintenance. This is the traditional approach of AM where assets are only fixed when they are broken (Henderson, Pahlenkemper and Kraska, 2014). Kiviniemi and Codinhoto (2014) report that reactive maintenance represents two-third of the daily asset maintenance operations of some asset owners. Reactive maintenance is usually a reactive strategy because maintenance actions or requests are only triggered by an unscheduled event of asset failure (Muchiri *et al.*, 2017). Reactive maintenance would cost more in the long-run as a result of the high cost of restoring the asset, damage, health and safety hazards inflicted by asset failure, and the loss of revenue associated with asset downtime (Tsang, 1995). This intervention strategy is ideal for inexpensive elements and those that are easy to replace. Reactive maintenance events have a negative impact on planned maintenance because these events completely disrupt planned maintenance schedules (Kiviniemi and Codinhoto, 2014).

2.4.2.3 MAINTENANCE BASED PRACTICES

Muchiri *et al.* (2017) classified maintenance practices according to their core function, and further distinguished their policies and their related practices: Failure based maintenance (FBM) – Reactive; Time based maintenance (TBM) – Preventive; Condition-based maintenance (CBM) – Predictive; Design-out maintenance (DOM) – Proactive; Opportunity-based maintenance (OBM) – Passive. These are maintenance management approaches to executing maintenance requests. A maintenance request is a work-order processed by any department in an organisation stating the need for a remedial activity to be performed on an asset. The department responsible for managing assets of which the asset manager oversees is usually domiciled within owner-operator organisations, but in some cases, these activities are outsourced.

Essentially, FBM is reactive maintenance as described in Section 2.4.2.2. TBM, on the contrary, is the maintenance approach where asset maintenance takes place at fixed intervals. In other words, maintenance activities are based on scheduled time intervals. For example, a maintenance task to apply certain treatments to assets weekly, monthly or annually. A TBM task usually requires intrusion into the asset, thereby, rendering it inoperative until maintenance is completed. These interventions are carried out to prevent or stop unplanned asset failures.

CBM is as a maintenance strategy that uses direct monitoring of the mechanical condition of an asset. System efficiency monitors and other indicators are used to predict the actual time to failure or loss of efficiency of an asset (Tsang, 1995). CBM is also referred to as on-condition maintenance, condition-directed maintenance, or predictive maintenance. CBM is a maintenance approach for attending to an asset when the need arises. This approach does not normally involve intrusions into the asset, and the actual preventive maintenance action is only performed when it is believed that an imminent failure has been detected (Tsang, 1995).

DOM is defined as the *'maintenance tactic whereby changes or modifications are done to the equipment to remove a failure cause, or to allow other maintenance strategies to be applicable in managing the consequence of the failure'* (AMBoK, 2014: 1). This involves the re-designing of intervention strategies through reducing stress on assets, thereby increasing the time to a failure event. DOM aims to redesign elements of an asset that consume high organisational resources and have unacceptably high failure rates (AMBoK, 2014). In other words, this means designing-out maintenance events through the creation of a reliability-based operational system. For example, to redesign a particular element that will strengthen the structural integrity in a way that no further maintenance will be required. DOM is usually a one-off activity.

OBM is defined as a systematic method of collecting, investigating, preplanning, and publishing a set of proposed maintenance tasks and acting on them when there is an unscheduled failure or repair opportunity (Savic, Walters and Knezevic, 1995). This maintenance strategy involves the development of a plan of action to exploit the opportunity that a failed asset brings so that certain unplanned preventive maintenance tasks can be carried out on exposed elements within the period of restoring the asset (Samhouri, 2009). Activities such as tests, information gathering and upgrading of the asset can be carried out during the period of asset downtime. This enables asset managers to make key decisions on repair and replacement of defective elements of an asset based on cost-effectiveness compared to probable future failure.

However, it is important to note the limitations of the above AM practices for the asset owner. The ability to predict failure is low, and restoration costs can be high in FBM. The TBM approach fails to account for performance time relationship and may not accurately represent asset service and performance levels (Khurshid, Irfan and Labi, 2011). Time-based strategies may fail to identify the appropriate time for an intervention because it usually occurs later or earlier than the expected time. CBM, on the other hand, requires advanced knowledge on the instrumentation of the asset, and this can lead to high initial costs. In adopting DOM, it is difficult to properly ascertain and isolate the elements responsible for the high cost of maintenance against the cost of redesigning. OBM has the tendency for over-maintenance resulting in high asset maintenance budgets. Also, this maintenance strategy has a time limit for opportunistic interventions to be made. In other words, if an organisation has a tight schedule, it may not be able to fully utilise such opportunities within the available time frame.

Consequently, there is a need for this study to investigate the AM systems of asset owners that are adopters of BIM-based processes in order to identify key business activity systems that impact on value creation, value management and value realisation through AM practices (Chapter 7).

2.4.3 ASSET REGISTER

An asset register contains all the assets owned by an organisation. Details of the value, type, function and location of assets are specified in the asset register. For most organisations, the asset register is the core element of their AM systems because it holds the database of information regarding every asset. The register facilitates the quick retrieval of asset information by managers for daily operations. Furthermore, the asset register may consist of two parts; financial and maintenance. The financial asset register contains information that relates to the current worth of assets and total ownership costs. This could be the purchase cost of assets, current value of assets after depreciation, operating and maintenance costs. On the other hand, the maintenance section of the asset register provides a structure for handling a wide range of information that is required to support the maintenance of assets. This could be the asset type, asset capacity, drawings, specifications, manuals, suppliers, maintenance instructions, maintenance history and failure history. Consequently, asset managers must ensure that records are reconciled between the financial asset register and maintenance asset register.

Despite the significance of the asset register and its role in AM, there is no industry standard that could guide asset managers through the whole process of developing the standard classification of assets within the register. ISO 27001 (2013) only provides a framework for asset owners to develop asset inventory, nomination of asset owners, the definition of asset use, and safe and secure management of information. Hence, the need to further explore how asset registers are utilised in relation to BIM-based AM processes (Chapter 5).

2.4.4 ASSET HIERARCHY

Asset hierarchy is the technique for classifying assets into groups on an asset register. The asset hierarchy can be based on asset type or asset function or both. The purpose of the hierarchy is to provide a framework for collecting and reporting asset information through some procedural standards in an organisation. The hierarchy denotes different levels at which asset information can be reviewed for critical decisions. Similarly, asset hierarchy management is a process of tracking every asset and their associated location in an organisation. Usually, this represents a family tree type relationship of the asset portfolio. The assets are drawn to denote relationships between assets and constituent elements such as spaces, equipment, processes and physical locations. These techniques of management classifications make it easier for asset managers to collect data, analyse and plan for asset interventions.

Most asset owners operate with informal asset hierarchy systems (Lin, Gao and Koronios, 2008). This leads to administrative problems with incorrect or insufficient data for critical decision-making. Some of the key aspects of asset hierarchy classification are asset class, asset group, asset type and asset parameters. Asset hierarchy systems can have several levels of categorisations based on asset number, equipment number, location, type, function and process. Typically, the naming is defined with consistent naming formats. The use of consistent standard naming conventions has enabled asset managers to integrate their registers with computerised systems, thus, enabling the organisation to conduct speedy searches of asset information within the AM system. For example, AB 01 BF AHU36 may represent; AB- Ancillary Building, 01 – Space Reference, BF – Basement Floor, AHU – Air Handling Unit, Asset Number – 36.

Although, the establishment of a standard asset hierarchy system has been highlighted to have huge significance in relation to AM business processes (Lin, Gao and Koronios, 2008), there is a need to provide guidance to asset owners on how to effectively approach the problem. Hence, the need to further explore how asset hierarchy systems are designed and utilised in relation to BIM-based AM processes (Chapter 5).

2.5 ASSET INFORMATION MANAGEMENT (AInfM)

Asset information is created from the action of users in performing AM tasks through the use of techniques, systems and technologies over the lifecycle of assets. Asset information that is created from these processes may be the actual intended output, produced for a corresponding task or consumed within the same task. This consideration makes Asset Information Management (AInfM) a crucial business process for asset owners. Koronios, Lin and Gao (2005) suggest the use of tools such as Computer-Aided Design (CAD) systems, DMS, EAMS, CMMS and PAMS in the creation and management of asset information. This study defines AInfM as a set of integrated processes, techniques and technologies involved in collecting, organising, storing, controlling, analysing securing, sharing and reporting asset information across various sets of information models, in one database or across many databases, from handover to the disposal of a facility.

Furthermore, Ouertani, Parlikad and Mcfarlane (2008) suggest AInfM involves two main activities; data capture and data management. The main objective of AInfM is to have the right information, at the right time, in the right place and in the right format for managers to execute their tasks. A good AInfM strategy supports asset managers to develop a set of plans for the efficient and effective management of an asset over its lifecycle. A poorly designed AInfM system may produce high amounts of unrefined data that would make it difficult for asset managers to get the right information with which to make reliable decisions on their assets. Amongst other factors, this could be as a result of non-organised information processes (Mirarchi *et al.*, 2018). Whilst implementing an AInfM strategy, asset managers have to observe the entire system and evaluate its effectiveness in comparison to expected performance (Koronios, Lin and Gao, 2005). Consequently, the quality of information produced by the system has to be continuously assessed and improved for an asset owner to achieve a reliable AInfM system.

The task of producing and managing asset information is a complicated one because of the diverse range of users and systems, each with specific requirements. Therefore, a comprehensive AInfM strategy is necessary in understanding how these large sets of disparate asset information can be collected, analysed, stored, managed and reported right through the lifecycle of an asset. This strategy would help asset owners derive value from their investments. Consequently, this study focuses on business processes performed by asset managers to optimise physical assets, including built assets within the domain of an AInfM system (Chapter 6).

2.5.1 STRATEGIES OF AInfM FOR ORGANISATIONS

Successful AInfM strategies are centred on effective control of information management dynamics within the business system. Factors such as data identification, data collection, measurement systems, tools for analysis, interpretation of data and strategic level reporting are key to developing reliable AInfM systems. Ouertani, Parlikad and Mcfarlane (2008) suggest two approaches for asset managers to consider when developing an AInfM strategy, namely, top-down and bottom-up (Figure 2.4). Although, Smeds and Haho (2003) highlight the necessity to combine both top-down and bottom-up approaches for successful process development.

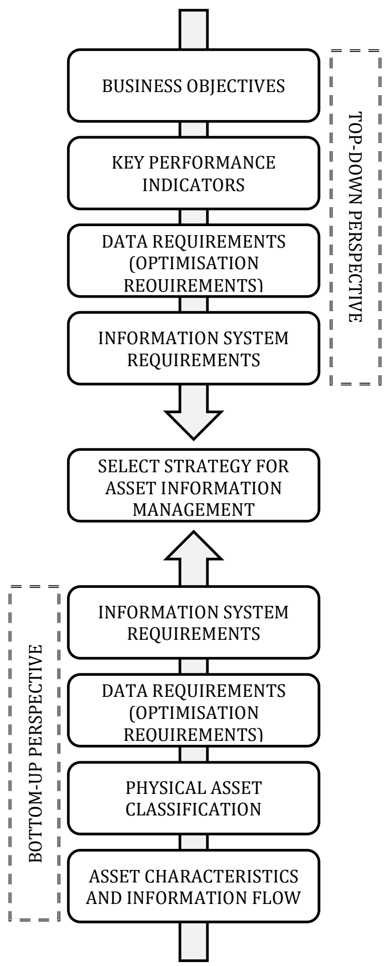


Figure 2.4: AIM design strategies (Adapted from Ouertani, Parlikad and Mcfarlane, 2008)

2.5.1.1 TOP-DOWN APPROACH

The top-down approach of developing an AInfM strategy is where the organisation understands and develops its information requirements to optimise assets based on organisational level business objectives (Ouertani, Parlikad and Mcfarlane, 2008). Arayici *et al.* (2011a) point out that higher-level management support is critical for the success of any change management strategy. However, one of the major drawbacks of the top-down approach is the resistance to change from the lower level management (Arayici *et al.*, 2011a). The top-down approach is done firstly by setting the organisational business objectives, which will inform certain Key Performance Indicators (KPI). These KPIs may be organisational objectives to minimise maintenance cost, reduce risks and improve ROI. The data requirements to be developed from the KPIs will be set exclusively for the optimisation of assets so as to achieve organisational objectives. The information requirements are compared with information quality, value of information and return on investment. This is done to determine the most effective organisational strategy for AInfM. To derive business value, asset owners need to develop a holistic management view of their assets by developing optimal operational maintenance management strategies.

2.5.1.2 BOTTOM-UP APPROACH

The bottom-up approach of developing an AInfM strategy is where the organisation understands and develops its information requirements based on the characteristics of the asset (Ouertani, Parlikad and Mcfarlane, 2008). Arayici *et al.* (2011a) argue that the bottom-up approach helps in engaging people, improving understanding, supporting change management strategies, and reducing potential resistance to change. Also, the integration of systems and processes is a key requirement for developing a complete AInfM solution (Koronios, Lin and Gao, 2005). However, the disadvantage of the bottom-up approach is that it is much more time and effort consuming (Arayici *et al.*, 2011a). The bottom-up approach is one of backward integration in developing organisational BIM-based requirements. Here, the organisational asset characteristics and information transactions are analysed in great detail in order to address issues related to the understanding of asset classification and asset attributes (Ouertani, Parlikad and Mcfarlane, 2008). For asset managers, the requirements of managing an air handling unit is different from that of

Information and Communications Technology (ICT) equipment. Data requirements for the optimisation of assets are collected, and strategies are developed. Collective strategies for assets are pooled together and are set side by side against information quality, the value of information and ROI to determine the most efficient AInfM strategy for designated assets. These strategies are then synthesised to form an organisational AInfM strategy.

2.6 BUILDING INFORMATION MODELLING (BIM)

The introduction and definition of BIM is necessary because the term is ambiguous and means different things depending on the context of its application (Aranda-Mena *et al.*, 2009). There has been inconsistency in the definition and meaning of BIM in the AEC industry. It is commonplace that prior to any intellectual discourse on BIM, the contextual definition is presented initially. Tse, Wong and Wong (2005) describe BIM as a powerful tool for the production of drawings in the AEC industry. In contrast, Eastman *et al.* (2011: 586) define BIM as '*a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation*'. The study goes on to state that BIM can accurately capture the entire geometry and characteristics of a building in a single building model. While, Succar, Sher and Aranda-Mena (2007: 308) explain BIM as '*a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle*'. Furthermore, Aranda-Mena *et al.* (2009: 2) distinguishes between the three perspectives of BIM: the first view assumes that '*BIM is a software application*'; the second view believes that '*BIM is a process for designing and documenting building information*'; and the third view holds that BIM '*is a whole new approach to practise and advancing the profession which requires the implementation of new policies, contracts, and relationships amongst project stakeholders*'. It can be seen that all three definitions have portrayed the three differing perspectives of BIM. Similarly, another term that causes confusion amongst academics and industry experts is the constant interchange of the term '*Modelling*' with '*Management*' in 'BIM' to describe a systematic approach to the collection and utilisation of asset information throughout its lifecycle (Parsanezhad and Dimyadi, 2014). Furthermore, there is an industry-wide misconception of BIM capability, where an organisation is termed as BIM capable only if it has the ability to collaborate with stakeholders in a work environment integrated with 3D spatial data. Nevertheless, BIM can be utilised in AM without 3D geometry by leveraging on the building information provided, for example, by COBie (Construction Operations Building Information Exchange) within an integrated BIM-based AM system.

Against this background, BIM is defined as a set of interacting processes, people and technologies that produce a methodology to digitally manage the data of a building, its performance, planning, construction, and later its operation (Succar, 2009; Eastman *et al.*, 2011). Furthermore, the study views BIM from the perspective of Building Information Management, where all relevant information is integrated or linked within one or more consistent datasets. In other words, the application of BIM in an AM system, which is the lifecycle perspective. Based on this view, BIM can be seen to deliver the required data sets for asset managers for executing their business processes.

2.7 DIMENSIONS OF BIM GOVERNANCE

BIM governance is defined as the process of establishing set criteria for stakeholders' rights and responsibilities in managing an asset throughout its lifecycle using an intelligent building information model (Rezgui, Beach and Rana, 2013). A suitable structure of BIM governance is seen as the basis for an asset owner to increase business value and reduce risks when managing a BIM initiative (Love *et al.*, 2014). Rezgui, Beach and Rana (2013) researched approaches of BIM governance with the view of addressing implications related to various aspects of organisational policy, stakeholder maturity, capability and readiness. The exploratory study only focused on the nature of technical and socio-organisational barriers by addressing technical aspects of data management in relation to multi-disciplinary and multi-actor lifecycle dimensions of projects. Subsequently, Love *et al.* (2014) argue for the need of a BIM governance perspective whereby there is integration between the building information model and all activities throughout the asset's lifecycle. In line with this, Succar (2009) presents a framework that views BIM governance from three fields of activity; technology, process and policy. This complex interpretation embeds players and deliverables into the three fields of activity, hence, making it difficult for the asset owner to isolate the actors and deliverables to be able to track business value. Prodan, Prodan and Purcarea (2015) identify other dimensions, and they are; people, process and technology. This view identifies the organisational domain as the environment in which process, people and technology interact in organisational process improvement. Here, management is seen as having a crucial role in how employees are directed (people), activities are planned and controlled (process), and how organisational resources are set-up (technology). Similarly, Bosch, Volker and Koutamanis (2015) suggest three dimensions of BIM that are vital in managing BIM data in the operations and use phase, and they are; people, systems (technology) and process. Similarly, Alreshidi, Mourshed and Rezgui (2017) propose three elements of BIM governance: actors and team (people); contracts, processes and legal frameworks (process); and data management and ICT (technology). This view puts in perspective the BIM ecosystem, including the actors, requirements and standards for producing deliverables. The successful implementation and subsequent realisation of BIM business value depends on these factors. Therefore, this study adopts the view of people, process and technology as key dimensions of BIM governance (Bosch, Volker and Koutamanis, 2015; Prodan, Prodan and Purcarea, 2015; Alreshidi, Mourshed and Rezgui, 2017) (Chapter 7).

2.7.1 PEOPLE

This is the human aspect that is responsible for the right skills, knowledge, motivation, conditions to perform organisational activities (Prodan, Prodan and Purcarea, 2015). The human dimension sets in the leadership, human resource, governance controls and decision-making for executing BIM-based processes. People, in the context of this study, refer to organisational strategy, BIM implementation strategy, collaboration, and staffing training and capability.

2.7.2 PROCESS

This is a set of conventions that regulate and coordinate organisational activity through established business processes. The process dimension provides organisational policies, standards, protocols, workflows and defined requirements for producing products and services using BIM-based processes throughout an asset's lifecycle (Alreshidi, Mourshed and Rezgui, 2017).

Process, in the context of this study, relates to BIM standards, organisational BIM objectives, defined roles, effective use of data, supply chain integration, asset lifecycle integration, and value realisation management.

2.7.3 TECHNOLOGY

These are tools and techniques that facilitate communication and simplify work (Prodan, Prodan and Purcarea, 2015). Technology as a BIM governance dimension emanates from hardware, software and networks as a set of IT artefacts that are utilised during data analysis or management for the production data or service (Succar, 2009; Brous, Herder and Janssen, 2015). These tools are the organisational infrastructure that provide a platform for collaboration, data exchange and data visibility through which BIM-based processes are executed. Technology, in the context of this study concern BIM systems, IT systems, AM systems, Facility Management (FM) systems, systems architecture, interoperability, data integrity and data accessibility.

2.8 BIM-BASED ASSET MANAGEMENT

BIM-based AM is the use of object-based information models and management techniques as decision support tools in digital AInfM to monitor and evaluate asset data for the purpose of asset optimisation. The main characteristics of BIM-based AM processes are those that relate to data management, storage, sharing and exchange in AM tasks, not 3D geometry as often thought in the context of BIM. These processes facilitate the utilisation of an asset information database to enable asset owners to enhance their operations and optimise the management of their assets.

Certainly, AM facilitates a holistic methodology that manages an asset from inception to disposal. With handover standards such as COBie that deliver structured information of the facility, asset managers have the ability to leverage asset data through BIM. The implementation of BIM in AM is an opportunity for asset owners to attain value propositions in their organisations through effective management of business processes (Love *et al.*, 2014). BIM implementation in the operations and use phase will require changes in business processes and development of new roles for asset owners to achieve the desired business value (Ayyaz *et al.*, 2012). These business modifications and resultant business value continuously change throughout a facility's lifecycle.

Some of the challenges asset owners face are cultural and operational in nature. That is, managing the change process and putting in appropriate measures for smooth implementation of BIM in AM. Without addressing these issues, an organisation may not be able to track the business value BIM generates. Similarly, Codinhoto and Kiviniemi (2014) suggest that asset owners need to be aware of their organisational inefficiencies in the first place before they can address technology-related challenges associated with BIM implementation.

A number of studies have focused on the implementation of BIM in the operations and use phase of built assets, but none has focused on BIM-AM integration. Becerik-Gerber *et al.* (2012) suggested application areas of BIM in the operations and use phase. However, this study does not provide BIM-based integration strategies in AM. Cavka, Staub-French and Poirier (2017) developed strategic requirements that will aid the asset owner in the transition from BIM to FM processes right through the handover of a facility. Whilst the study helps to inform asset owners in organising their requirements, it does not focus on the organisational-level strategic objectives of BIM implementation in AM. Similarly, Pishdad-Bozorgi *et al.* (2018) reported on the transition to BIM-based FM during the handover of a facility in a real-world case study. The study identifies: (a) the need for a clear definition of BIM-FM scope; (b) data collection through projects phases; and (c) smooth interoperability between BIM and FM tools; as criteria for successful implementation of BIM by an asset owner. Even though the study presents operational workflows for the management of information throughout a project's lifecycle, it however, does not suggest any strategic approach for an asset owner at the AM level. Ashworth, Tucker and Druhmann (2016) developed an FM to BIM concept model that outlines the process of preparing organisational BIM strategies based on stakeholder involvement. The study proposes how the facility manager can be integrated into the lifecycle project development of a built asset and how these processes link to the project phases, but it does not show how BIM-AM systems are integrated. Therefore, there is a need to further investigate existing strategies aimed at guiding asset owners in integrating BIM-AM systems.

On the other hand, Love *et al.* (2014) identified four significant aspects for asset owners to proactively manage the BIM implementation process in order to realise value from their investments. They are; governance, change management, stakeholder management and performance measurement. Although the framework is conceptual in nature, this study adopts this perspective (in Chapter 5) as a starting point with the understanding that if the four aspects of the framework are effectively managed during the planning and implementation of BIM in AM, an asset owner will be able to derive business value from BIM-based processes.

2.8.1 BIM-AM SYSTEMS AND DATA GOVERNANCE

Essentially, data generated from AM systems is only valuable to the organisation if users are able to interpret it into useful information within a particular context or for a specific task (Brous, Herder and Janssen, 2016). Love *et al.* (2014) suggest the need for asset owners to develop a governance perspective where BIM is integrated with projects, programmes and portfolios throughout the asset's lifecycle. Most organisations are unable to exploit the large amounts of available asset data into meaningful management information to enhance their operations (Lin, Gao and Koronios, 2008). This failure has led to the manifestation of silos of information in owner-operator organisations. Hence, asset managers have found it very difficult to utilise real-time asset data in their business operations. Also, asset managers need to be aware of complexities brought about by interoperability and ensure compatibility between systems, such as asset register systems, work-order management systems and condition monitoring systems when adopting BIM-based solutions for AM.

Lin *et al.* (2007) suggest some classifications within the context of governance and data management for asset owners based on technological, organisational and people perspectives. Similarly, Brous, Herder and Janssen (2015) researched the governance of data in a major owner-operator organisation. The study points out the need for the establishment of a department that is responsible for AInfM within the organisation. Furthermore, Brous, Herder and Janssen (2015) highlight the utilisation of Constructive Objects and the INtegration of processes and Systems (COINS) standard for BIM-based integration within the organisation. COINS is characterised by a container folder structure in the form of an object tree which ensures that GIS, 2D drawings, 3D models, IFC models and object type library are linked and stored in a database (Figure 2.5).

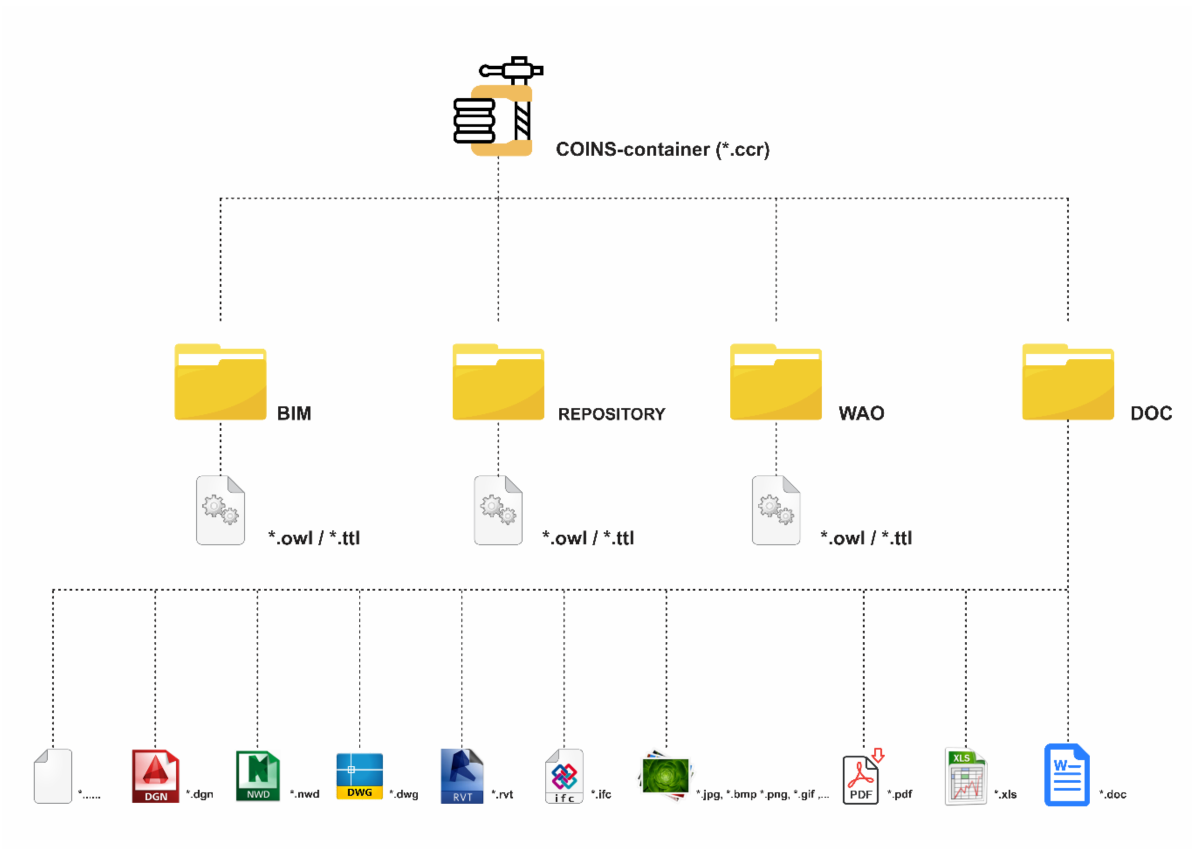


Figure 2.5: COINS container folder structure (DBIC, 2015)

Furthermore, Brous, Herder and Janssen (2015) goes on to propose a framework for asset owners to break down the silos of information and unlock trusted information to flow freely to where it is required in the organisation. The framework assesses how data governance affects completeness, consistency, accuracy, relevancy and timeliness of data. The study helps to demonstrate effective systems and data governance for asset owners. In the same manner, Campos *et al.* (2017) developed a framework on how asset owners can make well-organised decisions, plan and analyse data for AM functions through effective data governance. The framework is in three layers: (a) IT technologies and data sources; (b) Data analysis; (c) Data visualisation; which is aimed at assisting asset owners in converting operational data into information and knowledge that will result in increased business value.

2.8.2 BIM CHANGE MANAGEMENT

The adoption of BIM-based processes for AM tasks by any asset owner will involve a shift in organisational culture. This change in culture will bring about risks and challenges that must be managed to ensure successful implementation of new systems and subsequent attainment of organisational objectives. Good change management practices have to be adopted for asset owners to benefit from the opportunities and avoid threats that will be faced by their organisation when implementing BIM-based processes. Change management in this context refers to the technique and methodology put in place by an asset owner in order to achieve the desired outcome of a BIM initiative or project.

Due to the technological and organisational changes involved, proactive change management is required for asset owners transitioning from traditional AM systems to one supported by BIM (Jupp and Awad, 2017). This transition is usually constrained by the lack of consistent approaches. Jupp and Awad (2017) discuss two change management strategies for BIM implementation in the operations and use phase, which are; the deployment of a '*niche project with follow up*', and an '*overall step-by-step*' approach. On the other hand, Lewin (1951) proposed a three-step model to organisational change management. They are; unfreeze, moving and refreezing. Similarly, Kotter (1996) propose an eight-step technique for managing organisational change. They are: to establish a sense of urgency about the need to achieve change; create a guiding coalition; develop a vision and strategy; communicate the change vision; empower broad-based action; generate short-term wins; consolidate gains and produce more change; and anchor new approaches in the corporate culture.

2.8.3 BIM STAKEHOLDER MANAGEMENT

BIM provides opportunity for multi-disciplinary collaboration where all parties can effectively participate during project delivery (Eastman *et al.*, 2011). This approach provides the opportunity for asset managers, facility managers, end-users, and contractors to participate because of improved shared understanding during asset development and subsequent asset operation and maintenance. These stakeholders will have the potential to retrieve, update and modify asset information right through BIM-based processes. With this opportunity comes other risks or challenges to manage the contributions of all parties within a BIM-based environment successfully. Stakeholder management in this context refers to the tools and techniques used to successfully deliver a BIM project through active engagement of project participants.

To assist this process, there exists collaboration platforms that help manage the activities of stakeholders during BIM implementation. There are a number of vendors that provide software-based collaboration platforms for AM tasks such as CMMS, Common Data Environments (CDE), Integrated Workspace Management Systems (IWMS), Computerised Asset Management Software (CAMS), Computer-Aided Facilities Management (CAFM) and BIM (Codinhoto and Kiviniemi, 2014; Guillen *et al.*, 2016; Love *et al.*, 2016). These products allow stakeholders to monitor asset performance, activity and parameters during routine tasks. Thus, enhancing communication between stakeholders during project execution.

2.8.4 BIM PERFORMANCE MANAGEMENT

BIM-based processes will not only enhance the management of assets, but rather, they will provide an efficient mechanism for good information management throughout the organisation. Performance management in this context involves the set of managerial activities put in place to observe, monitor and evaluate organisational performance with the sole aim of attaining pre-set BIM-based objectives of good information management and value realisation. The success of the entire BIM process depends on the weakest contributor to the system (Walasek and Barszcz, 2017). The goals and targets of BIM implementation should be defined early in the process by the asset owner. In the same manner that a BIM manager is utilised during the construction process, the role of an information manager will have to be established for the BIM-based AM processes. The information manager will be responsible for the efficient and effective management of asset data and ensure interoperability in line with organisational and project objectives.

For business process performance to be measured, the BIM-based processes will have to be evaluated. This evaluation will enable asset owners to identify the productivity improvements that result from the implementation of BIM-based processes (Succar, Sher and Williams, 2012). Managing expectations is important during this process. Asset owners need to be realistic and not set ambitious targets that are not achievable. Also, another issue is that BIM adopters usually expect to realise significant business value while they are still inexperienced users (Succar, Sher and Williams, 2012). Better understanding of the BIM-based processes, the systems workings, and potential impact on the organisation will help managers during the initial stages of implementation.

To evaluate organisational BIM performance, Succar, Sher and Williams (2012) identified five components for asset owners to consider, and they are: BIM capability stages; BIM maturity levels; BIM competencies; organisational scales; and granularity levels. BIM capability refers to the basic ability of an asset owner-operator to perform BIM-based processes to execute AM tasks. The BIM capability stages represent the major milestones an owner-operator needs to attain in order to implement BIM-based processes continuously whilst improving on the previous stage. BIM maturity relates to the quality, repeatability and degree of excellence of BIM-based processes within a BIM capability towards executing AM tasks. This is the level of versatility an organisation possesses within a certain capability stage. BIM competency in an organisation refers to the individual competencies for assessing capability and maturity that can be classified into technology, process and policy (Succar, Sher and Williams, 2012). Organisational scales refer to the classifications of business sector, company size and markets. Lastly, granularity levels are assessment criteria grouped to the enhance BIM capability.

2.9 MATURITY MODELS IN THE AEC INDUSTRY

Maturity models originate from the software industry, which are aimed at increasing productivity and reducing defects through continuous improvement of organisational practices. Generally, most maturity models are based on the Capability Maturity Model (CMM), which was developed in response to poor project performance (SEI, 1994; SEI, 2006; Blommerde and Lynch, 2016). A maturity model facilitates the easy distinction between mature and immature processes in terms of an organisational approach to business processes (Sarshar *et al.*, 2000). The maturity levels indicate a scale for evaluating the capability of individual processes in an organisation. This indication helps an organisation to establish self-knowledge of its current process maturity and support continuous improvement. Despite the large number of maturity models available in existing literature, their objectives are highly similar.

Researchers have proposed a number of maturity models that are applicable to the AEC industry. One is the Structured Process Improvement for Construction Enterprises (SPICE) model (Sarshar *et al.*, 2000). The SPICE model presents various levels of maturity that aims to enable construction companies to improve their processes. Another is Construction Supply Chain Management (CSCM), which focuses on the management of information, costs and workflows in a construction project (Vaidyanathan and Howell, 2007). The CSCM aims to remove inefficiencies and improve operational excellence in the construction supply chain. Similarly, the Portfolio Programme and Project Management Maturity Model (P3M3) is a framework that organisations can use to assess current performance, enhance efficiency, improve project success and achieve value for money from project and programme procurements (OGC, 2010). Furthermore, Kwak and Ibbs (2002) present a Project Management Process Maturity $(PM)^2$ Model, which aims to integrate project management maturity models, processes and practices in order to improve effectiveness. However, the above maturity models are too generic and are not specific to BIM nor AM.

The National Institute of Building Sciences (NIBS) proposes an Innovation Capability Maturity Model (I-CMM) that is aimed at improving planning, design, construction, operation and maintenance processes using a well-established building information model (McCuen, 2008). The

I-CMM determines the maturity of a building information model against a set of criteria, of which there are ten maturity levels and eleven areas of interest (NIBS, 2007). Similarly, Succar (2010) proposes a BIM Maturity Index (BIMMI), which includes defined levels that signify the evolutionary development of BIM governance dimensions in an organisation. The BIMMI is based on the CMM and has five stages; Ad-hoc, Defined, Managed, Integrated and Optimised. These maturity levels express the developmental progress of organisational processes within a particular BIM capability or stage (Succar, 2010). The maturity levels reflect BIM capability, performance targets, implementation requirements, and quality management indicators (Succar, 2009). As such, the progression from low to greater levels of maturity highlight better control, predictability and effectiveness in reaching defined goals within an organisation. The BIMMI (Succar, 2010) development and application is based on a complex design of BIM lenses, BIM stages and BIM fields. Lenses are denoting layers of analysis, fields are referring to domains of activity, and stages are representing business process capability. Although the above maturity models are specific to BIM, they lack applicability in relation to AM and value realisation activities.

In summary, the review of literature establishes the need for a maturity model that is specific to the domains of BIM, AM and value realisation management. Although there is no comprehensive maturity model that applies to BIM in relation to AM processes and value realisation management, the study adopts the maturity scales proposed by the BIMMI (Succar, 2010) in developing a BIMAsset Maturity Model (BAMM) (Section 8.4.3).

2.10 BIMASSET AS THE FACILITY DIGITAL TWIN

Patrick, Munir and Jeffrey (2012: 4) define a BIMAsset as '*the combination of BIM technologies together with the updated facility information, models, associated links and references in an interoperable structure to be handed over to clients at the point of practical completion or at the point of sale*'. A BIMAsset is developed through the integration of accurate data of a facility over its entire lifecycle. The entire information of the facility may not necessarily be contained in one model, but the data could be linked in readable formats (Patrick, Munir and Jeffrey, 2012). As long as there is effective interoperability between the systems, it could enable-time information retrieval by the asset owner to efficiently manage asset data. A BIMAsset is created from the merging of accurate data captured from the collaborative origins of a project right through to handover and commissioning, which, if adequately maintained and kept current and accurate, has the potential to enhance the value of a property (Terreno, Anumba and Dubler, 2016).

Patrick, Munir and Jeffrey (2012) argue that a BIM-enabled facility is viewed as a secure investment owing to the ready availability of a richly populated data asset, making it highly marketable and reliable. This assertion is focused on pinpointing the business value of BIM to clients and that the virtual BIMAsset will have business value to the client if properly maintained and kept up-to-date. Patrick, Munir and Jeffrey (2012) suggest that the asset owner could derive some business value from the BIMAsset which is generated as a result of the enhanced value of the development brought about by asset data accessibility, accuracy, reliability and currency. Furthermore, these benefits can be carried forward for asset operations, modifications, marketing, sale and demolition.

The BIMAsset is sometimes referred to as the Digital Twin (DT). The DT is defined as a comprehensive description of the physical asset in a digital format that includes all the useful information in the entire lifecycle (Schleich *et al.*, 2017). Just like the BIMAsset, the DT is not one complete model of a physical artefact, but a set of interconnected engineering data, operational data and simulation models that evolve throughout the lifecycle of an asset (Boschert and Rosen, 2016). A DT consists of the following elements: real space; virtual space; virtual sub-spaces; data link from physical to virtual space; and information flow from physical to virtual space (Grieves and Vickers, 2017). Tao *et al.* (2018) note that a DT should have the following characteristics; real-time reflection, interaction and convergence, and self-evolution. Real-time reflection meaning the physical and digital spaces mirror each other. Interaction and convergence implying that there should be sufficient integration of both systems and workflows in the physical space, digital space, historical data and real-time data. Self-evolution refers to the ability of the DT to automatically read, comprehend, analyse and update itself in relation to the rate it receives data.

According to Grieves and Vickers (2017), there are two main classifications of DTs, and they are Digital Twin Prototype (DTP) and Digital Twin Instance (DTI). The DTP comprises of all the necessary informational sets required to demonstrate and produce a mirror version of a physical or virtual state (Grieves and Vickers, 2017). On the other hand, DTI is a virtual instance that describes a corresponding physical state linked to it throughout its entire lifecycle (Grieves and Vickers, 2017). Going by these definitions, the classification of the DT that the BIMAsset represents is the DTI. Similarly, this conforms with the definition of Patrick, Munir and Jeffrey (2012) above that the main purpose of the BIMAsset is to represent an instance of the physical asset including necessary real-time, current, past interrogative data including future predicted data required to maintain and operate the DTI. Predictive data meaning the BIMAsset could be utilised to forecast future asset behaviour, condition and performance. Interrogative data meaning the BIMAsset could be analysed for current and past histories of asset data. Nevertheless, the BIMAsset may have manifestations of the DTP, but this would be at the design and construction phases prior to handing over of the building information model, which excludes all necessary operational data.

Within the PLM industry, there are different understandings of the DT. Some use DTs for: (a) establishing a link between virtual and physical models to increase manufacturing flexibility and competitiveness (PTC); (b) setting benchmarks of product design performance (Dassault Systèms); forecasting lifecycle asset condition and performance (General Electric); (c) enhancing efficiency and quality (SIEMENS); (d) developing a factory virtual twin of the actual physical product by synchronising data transmission between the product and factory (TESLA) (Schleich *et al.*, 2017). This concept of DT or BIMAsset applies to the AEC industry, where there exists the physical structure (physical spaces) and the building information model (virtual space) including data links and information flow.

The BIMAsset has the potential to derive business value for the asset owner in asset operations considering its characteristic, primarily its synchronous nature. Patrick, Munir and Jeffrey (2012) suggest that the BIMAsset may help the asset owner in reducing survey costs, improve decision-making, increase the confidence level in assets, enhance accurate forecasting, reduce maintenance cost, engender ease of tendering and enhance compliance with statutory obligations. In spite of these potential benefits to asset owners, there have been limited studies regarding the exploration of the BIMAsset in the AEC industry. Hence, the need to develop a value realisation model in relation to the BIMAsset (Chapter 8).

2.11 BIM-BASED INFORMATION REQUIREMENTS

PAS1192-3 (BSI, 2014a) suggests the need for information requirements and the development of an information model for the operations and use phase. Similarly, PAS1192-2 (BSI, 2013) recommends a structured definition of the owner's requirements in building and infrastructure projects. In the same manner, Becerik-Gerber *et al.* (2012) suggest a framework for the data structure of non-geometric data requirements. However, Jupp and Awad (2017) highlight challenges in the development of BIM-based information requirements, they are: (a) development of a vision for BIM-based processes; (b) definition of required data and formats; (c) identification and definition of storage processes protocols. Furthermore, PAS1192-3 (BSI, 2014a) presents the relationship between elements of BIM-based information management such as EIR, Organisational Information Requirements (OIR), Asset Information Requirements (AIR), Project Information Model (PIM) and AIM. This is shown in Figure 2.6, whilst their relationship in relation to the asset's lifecycle is shown in Figure 2.7.

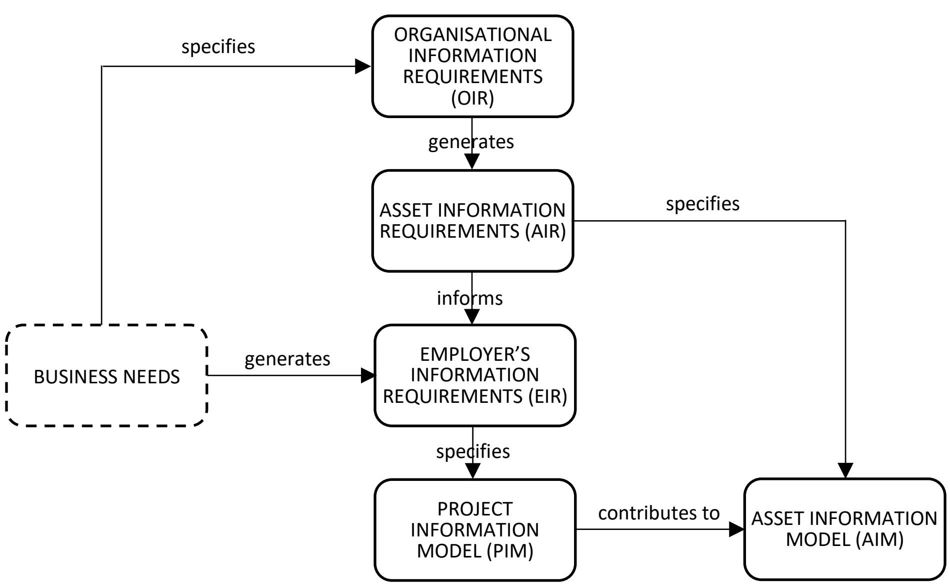


Figure 2.6: Elements of BIM-based information management adapted from PAS1192-3 (BSI, 2014a)

The process starts with the OIR, where the asset owner probes the business needs to identify the data and information required from the BIM-based processes in order to meet the needs of its AM system and other business functions (BSI, 2014a). These are organisational-level information requirements that are documented from different levels of the organisation. It is important for asset owners at this stage to develop business cases and to identify the anticipated business value of implementing BIM-based processes at every level of the organisation.

The next step is the development of the AIR, where the asset owner probes the OIR in relation to the organisational assets in order to identify the information requirements for BIM-based processes (BSI, 2014a). These are asset-level requirements for executing AM tasks within owner-operator organisations. The AIR is a document that specifies the asset owners' information requirements for establishing an AIM (Patacas, Dawood and Kassem, 2016). It is necessary for asset owners to develop a deep understanding of their OIR and AIR in order to develop robust information requirements that will respond to business needs and derive BIM business value.

PAS1192-2 (BSI, 2013: 3) defines EIR as a '*pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process*'. The AIR forms the basis for the EIR, whilst the EIR is a significant tool for the client that aims to ensure that the right information is delivered in the right format and at the right time in the BIM process from tendering to asset operations. An EIR consists of: standard methods and procedures on information formats; clear definition of information-related roles; information delivery plan; recognition of the asset owner's existing CMMS; and a COBie demand matrix (BIFM, 2017).

The PIM represents the '*as-built*' digital representation of the physical asset. This is developed progressively during the design and construction phases and handed over at the closeout. The PIM is developed as specified by the EIR, and forms the basis for the AIM. The PIM contains data which should be kept '*as-is*' by the asset owner. This contains the current information of the facility, which is generally used as a reference model. The PIM is kept '*as-is*' because it contains some information that is needed when making changes to the facility but may not be required for day-to-day operations.

An AIM is a graphical and non-graphical document, which consists of the data components of physical assets required to operate an asset and to provide organisational AM system support (BSI, 2014a; Patacas, Dawood and Kassem, 2016). An AIM can be managed as a single asset model or a collection of models linked to EAMS (Talamo and Bonanomi, 2015). The asset information model is vital to the asset owner as it provides a data repository and means for accessing and retrieving information (Patacas, Dawood and Kassem, 2016). The AIM comprises the data defined in the EIR and comes from the PIM. Also, the information from the AIR is used to specify the AIM. In the information management process, the purpose of the AIM is to satisfy both AIR and OIR, thereby ensuring that business value is realised by the asset owner. The study defines the asset information model as a set of integrated datasets, in one model or in different connected models, containing the essential attributes of the physical assets contained in a facility. These datasets may include or have links to 3D geometric data.

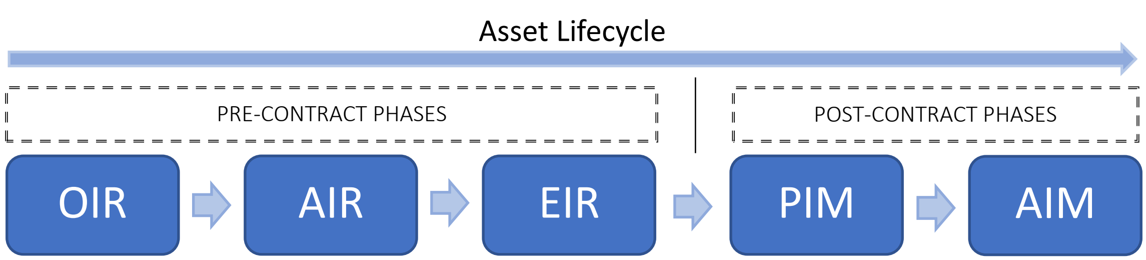


Figure 2.7: Elements of information management in relation to the asset's lifecycle

Despite the fact that PAS 1192-3 (BSI, 2014a) presents a framework for the definition of elements contained in the information model, it does not cover the development of operational information requirements, OIR and AIR (Patacas, Dawood and Kassem, 2016). Also, asset managers are aware of the need to plan and request the information needed at the point of handover in relation to

BIM-based processes, but they are ignorant of how to approach the problem (Ashworth, Tucker and Druhmann, 2019). Generally, there is a lack of understanding in the AEC industry concerning the approaches to develop operational information requirements and the subsequent monitoring and evaluation of data deliverables during the lifecycle of a facility in order to derive BIM business value. As a result, there is a need to investigate strategies, tools and techniques utilised in developing operational information requirements for BIM-based processes in order for asset owners to derive BIM business value (Chapter 4).

2.12 BUSINESS VALUE OF OPERATIONAL INFORMATION REQUIREMENTS FOR BIM-BASED PROCESSES

For effective AM processes, asset managers need data that are reliable, accurate, consistent and timely in order to execute their tasks. A poor understanding of information requirements amongst managers in terms of the level of detail, nature of data, and format required has affected the momentum of BIM in asset operations and hindered the subsequent value realisation by asset owners (Parsanezhad and Dimyadi, 2014). Essentially, AM is focused on the establishment of a coordinated set of activities for an organisation to realise value from assets (IAM, 2012). As such, these cannot be effective AM without it being responsive to business needs. Business needs are referred to as requirements (operational and strategic) that drive organisational processes in order to achieve business objectives. In this context, business needs refer to AM requirements that facilitate the utilisation of reliable data provided by BIM-based processes in order for an asset owner to achieve business objectives.

Certainly, there is increasing evidence of BIM business value in AM (Cavka, Staub-French and Poirier, 2017). In spite of this, AM business needs in relation to information requirements have not been extensively studied in order to realise BIM business value (Becerik-Gerber *et al.*, 2012; Volk, Stengel and Schultmann, 2014; Korpela *et al.*, 2015). In an effort to identify these requirements, Becerik-Gerber *et al.* (2012) highlight areas of BIM implementation in the operations and use phase that could create business value for asset owners by defining their business-level data requirements. Similarly, Cavka, Staub-French and Poirier (2017) develop an iterative approach to identifying information requirements through linkages with business needs. This aims to formalise the process so that asset owners can derive value from BIM-based asset data. Also, there have been efforts to develop and test an EIR template, including a guidance document designed to meet the organisational business-level needs of BIM-based processes (Ashworth and Tucker, 2017a; Ashworth, Tucker and Druhmann, 2017b). As a criterion, Brous, Herder and Janssen (2016) suggest that data governance programmes should aim to demonstrate business value. Hence, developing the understanding of asset owners in identifying critical BIM-based operational information requirements for AM business processes is important.

Furthermore, management-level executives are doubtful of whether data used within owner-operator organisations is reliable, consistent, accurate and timely enough to enhance critical decision-making (Koronios, Lin and Gao, 2005). Similarly, Lin *et al.* (2007) assert that there is a data gap between the asset developer and user because sufficient data quality levels are usually not met to enable effective AM. In a bid to address these shortcomings, some asset owners have developed data management units which implement and enforce data management protocols organisation-wide to ensure effective BIM implementation in asset operations (Brous, Herder and Janssen, 2015).

In addition, there are many barriers that hinder the development of information requirements and realisation of business value in asset operations because the development of operational information requirements that inform the physical product including the digital representation remains a significant challenge (Becerik-Gerber *et al.*, 2012; Cavka, Staub-French and Poirier, 2017). Similarly, owner information requirements are not expressed in computable formats to enable BIM-based delivery (Cavka, Staub-French and Poirier, 2017). Also, efforts to develop requirements fall short of the contextual nature of AM (Love *et al.*, 2014; Cavka, Staub-French and Poirier, 2017). Although recently, AM and FM systems enable accurate and timely delivery of geometric and non-geometric model-based data for the execution of business processes. Therefore, there is a need for strategic identification of operational information requirements by the asset owner in order to enhance BIM-based AM activities (McArthur, 2015).

Early engagement of AM professionals in the BIM processes has been suggested to overcome some of the information requirement and delivery challenges, but it is rarely achieved in practice (Wang *et al.*, 2013). Ashworth, Tucker and Druhmann (2017b) highlight the need for specific guidance on preparing EIRs in order to develop a deep understanding of asset owners in relation to business needs and in connecting them to organisational BIM strategy. This is to ensure that the right information is handed over for asset operations (Ashworth, Tucker and Druhmann, 2016). Asset owners need to develop a better understanding of organisational prerequisites, such as defining operational information requirements in order to enable positive effects that derive BIM business value (Vass and Karrbom Gustavsson, 2014b). Mayo and Issa (2014) suggest the need for a thorough review of business needs to identify the datasets that provide business value for the asset owner through BIM-based processes. The resolution of the problem is highly dependent on how asset owners articulate their requirements. Therefore, the question of what information asset managers require to do their work through BIM-based processes still remains unanswered (Giel and Issa, 2016). Hence, there is a need to identify critical BIM-based operational information requirements for AM business processes (Chapter 4).

2.13 BIM BUSINESS VALUE REALISATION MANAGEMENT

A number of studies have interchangeably used '*Benefits Realisation*', '*Benefits Realisation Management*' and '*Business Value Realisation*' for determining the business value of BIM, IT and Information Systems (IS) in a business ecosystem (Tillmann, Tzortzopoulos and Formoso, 2010; Masli *et al.*, 2011; Love *et al.*, 2014; Serra and Kunc, 2015). Against this background, this study adopts the term business value realisation. On the other hand, the benefit is defined as '*an outcome of a change that is seen as positive by a stakeholder*' (Bradley, 2010: 39). IT business value is the sustainable benefit realised by an organisation through IT-based systems, either by collective or individual systems, assessed from an organisational perspective (Cronk and Fitzgerald, 1999). Consequently, value realisation is the process of evaluating these benefits. Value realisation management is defined as *'the process that realises the benefits that are achieved and manages the unexpected ones'* (Farbey, Land and Targett, 1999: 241). Business value realisation is an initiated logical process to ensure that change takes place and the positive output is measured and acknowledged in relation to how it benefits the organisation. Therefore, business value realisation is a strategy adopted by an organisation to determine how benefits are realised, at what level and when. The main purpose of value realisation is not to forecast benefits but to make them come true (Ward, Taylor and Bond, 1996).

Many studies on business value realisation have tried to address the issue of realising the business value of IT-based investments, but the problem is a dynamic one. Andersen *et al.* (2000) present a procedural value measurement framework for IT-related investments in the AEC industry. Similarly, in a bid to address the complex issues of value realisation, Sapountzis, Harris and Kagioglou (2007) review four value realisation management approaches and propose a value realisation framework that is integrated with business and investment processes in order to support organisations in the optimisation of business value from investment programmes. Furthermore, Ashurst and Doherty (2003) suggest the best practice for value realisation through the development of a conceptual framework. Similarly, Ward, Taylor and Bond (1996) adopt a procedural approach and explains the steps within the value management process. On the other hand, Leyton (1995) propose a model which approached value realisation from the perspective of business change.

The main challenge of realising BIM business value is that asset owners do not plan to realise benefits in the first place. Value realisation has to be conducted deliberately and consciously. Some asset owners harbour the *'silver bullet thinking'* on BIM investments (Thorp, 1998; Thorp, 2001). That is, if they invest in BIM, the business value will come automatically. Lin and Pervan (2003), suggests the need for asset owners to change their strategy of business value realisation from a passive approach to a more proactive one. Love *et al.* (2014) further assert that BIM alone cannot deliver business outcomes and that the process of its implementation has to be proactively managed to ensure that the organisation realises the business value it expects. Irrespective of the primary strategic objective for adopting BIM, an organisation will have to understand its capability and maturity before it can realise any value from the whole process. Hence, the need to develop a BIM business value realisation model and maturity model for asset owners (Chapter 8).

2.13.1 BIM BUSINESS VALUE

In this study, value refers to a service or outcome that is of economic benefit to an asset owner (Weigand *et al.*, 2006). This may be tangible or intangible value. As such, the notion of value in this research is economic. In identifying BIM business value, the main issue of contention for asset owners is how to identify the benefits and the methods with which to measure them. A number of studies have attempted to identify the business value of BIM in the operations and use phase. Ding *et al.* (2009) find that BIM-enabled facilities management yields a 98% reduction in time used to update asset databases. Similarly, Codinhoto and Kiviniemi (2014) identify 13 metrics of BIM business value in the operations and use phase. Similarly, in a bid to evaluate the business value of IT-based investments, Willcocks and Lester (1996) propose a balanced score card (BSC) approach to examine the contributions of IT-based investment from the financial, internal business, innovation and learning, and customer perspectives. However, this method does not provide for an aggregate system for these factors, as the decision of worthiness of an investment still remains with the asset manager. On the other hand, Construct IT (1998) identify different IT business value and classifies each benefit against three factors: (a) efficiency assigned with a financial value; (b) effectiveness defined with a subjective value; and (c) performance qualified with qualitative accounts; however, with no quantification. The values were also classified according to the business processes they support. Also, Gartner (2003) present a five-pillar benefit realisation framework; strategic alignment, business process impact, architecture, direct payback, and risk. The framework determines the overall business value expected to be created by an IT-enabled business initiative. It uses a standard set of concepts for quantitative and qualitative value methods. The Gartner framework provides an aggregate score card for IT-based investments. Melville, Kraemer and Gurbaxani (2004) propose an IT business value model that uses a resource-based view (RBV) to focus on the impact of IT-based investments such as BIM on organisational resources and business processes. Similarly, Love *et al.* (2014) present a framework that asset owners can utilise to realise value from investing in BIM. The framework adopts governance, change management, performance measurement, and stakeholder management as factors that enable the strategic alignment of the asset owners' business strategy. However, the framework does not provide a scoresheet for aggregating the key factors. Furthermore, Sanchez, Mohamed and Hampson (2016) present an eight-step BIM value realisation framework that introduces a methodology together with a benefits, metrics and enablers dictionary to aid measurement. However, the framework focuses mostly on tangible and semi-tangible value while ignoring intangible value.

Deriving business value from an IT-based system can be difficult and depends largely on many different complex factors that cannot be controlled or isolated for formal experiments (Bakis *et al.*, 2006). This is because the workings of an organisation are a collection of various integrated systems to perform tasks and deliver outputs. It is not possible to isolate BIM from other closely interconnected processes in order to assess it, or one independently of the other. Another reason why it is difficult to objectively prove the business value of a BIM-based investment is because an IT system only has the potential to create value, and not direct value in its own right (Mooney, Gurbaxani and Kraemer, 1995; Farbey, Land and Targett, 1999; Remenyi, 2000; Love *et al.*, 2014). Another argument is that an IT-based investment may not yield the desired business value simply because it is not well implemented (Brynjolfsson and Hitt, 1998). On this premise, there appears to be a need for identifying the business value of IT-based investments such as BIM. Therefore, further research is needed to develop techniques for tracking the tangible and intangible value of BIM-based processes in AM (Chapter 8).

2.13.2 BIM VALUE MEASUREMENT TECHNIQUES

There are many value measurement techniques that can be used by asset owners to identify the value that BIM affects. Some techniques are generic, while some may be unique to certain organisations. The study explores four value measurement techniques; ROI, savings to investment ratio (SIR), KPI and process mapping. However, this study is exploratory and does not aim to implement these techniques in a use-case nor to test their application in AM but to improve the understanding of asset owners on available techniques of BIM business value measurement and their applicability. It is worth mentioning that an organisation may utilise multiple methods to measure BIM business value. Also, Love *et al.* (2013) argue that if financial techniques such as ROI are only used to justify investments in BIM, then the entire process is limited to financial management. Therefore, there is a need to explore and determine how some established economic value measurement techniques can be used to track and measure tangible and intangible BIM business value in AM (Chapter 8).

2.13.2.1.1 RETURN ON INVESTMENT (ROI)

ROI is defined as the ratio of resources gained or lost in a process or investment, as against the total amount of resources provided (White, 2007). A positive ROI indicates that more benefit than cost was generated and a negative ROI indicates that less benefit than cost was generated by the investment or process. ROI is one of many available techniques for evaluating proposed investments by comparing potential benefit or gain from an investment against the cost. It is used to compare investments with different lifespans through an equivalent annual cost method. In other words, ROI is a method of evaluating investments in relation to profit and capital invested.

When applied to BIM, it is suggested that positive ROI means business value to clients, contractors, consultants and other stakeholders and measurement to be calculated as a ratio of benefit to cost (Giel, Issa and Olbina, 2010). ROI is calculated as:

$$ROI = \frac{Gain\ from\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment}\ \text{x}\ 100$$

There have been a number of attempts aimed at capturing the business value of BIM-based on ROI (Azhar *et al.*, 2008; Giel, Issa and Olbina, 2010; Teicholz, 2013; Autodesk, 2016; Guerriero, Kubicki and Reiter, 2016; Scottish Futures Trust, 2017; Walasek and Barszcz, 2017). Autodesk (2016), proposes a strategic framework for calculating ROI for BIM. Similarly, Walasek and Barszcz (2017) identifies the business value of BIM-based on reduction in costs and its effect on ROI. Azhar *et al.* (2008) identifies and quantifies the business value that BIM brings alongside details of project scope. The study goes on to illustrate net BIM savings and ROI. Giel, Issa and Olbina (2010) shows the benefit derived through ROI calculation on a BIM delivered the project as against an earlier project without BIM. Similarly, Guerriero, Kubicki and Reiter (2016) presents a structured method for the assessment of BIM ROI. Also, Teicholz (2013) uses an ROI analysis for BIM integration in the operations and use phase. Furthermore, Scottish Future Trust (2017) adopts a BIM-ROI calculator to help asset owners see the business value that may be derived from BIM-based processes and in developing business cases for BIM implementation.

One of the challenges of using this method to measure business value is the lack of an industry-wide accepted benchmark for measuring BIM ROI (Giel, Issa and Olbina, 2010; Neelamkavil and Ahamed, 2012). Another problem is the inapplicability to generalise or compare ROI data because it is hardly ever possible to find two organisations using the same business processes and accounting policies.

2.13.2.1.2 SAVINGS TO INVESTMENT RATIO (SIR)

SIR represents the ratio of savings in relation to the investment. It can be used to evaluate whether potential savings of a project justifies the initial investment. The important factors when using SIR are investment cost and functional asset effectiveness (Ağra, 2011).

When applied to BIM, an asset owner can determine whether the proposed savings in a BIM business case justifies the cost of the total investment. SIR involves the following processes: Determining the cost of the project; Determining the useful life of the asset; Determining the savings associated with the project; and Calculating the ratio. SIR is calculated as:

$$SIR = \frac{PV(Internal\ Project\ Cost\ Savings) + PV(Programme\ Cost\ Savings)}{PV(Initial\ Investment)}$$

PV here refers to the present value. One of the challenges of adopting this method to measure business value is the meticulous nature of identifying savings in relation to the total investment and comparing it with alternative options. This task requires a great deal of skill to execute but can be very beneficial to the asset owner if done correctly.

2.13.2.1.3 KEY PERFORMANCE INDICATORS (KPI)

KPIs are a set of quantifiable measures that an organisation uses to evaluate or compare performance in achieving strategic and operational objectives. KPIs are collections of data measures used to evaluate the performance of a system, task, or construction operation (Cox, Issa and Ahrens, 2003). Data measures in KPIs can be actual, forecast, estimated, or established quantities. Economic evaluations using KPIs usually compare actual against estimated performance with reference to efficiency, effectiveness, quality of outcomes and workmanship. KPIs can be used to assess both tangible and intangible value through quantitative and qualitative performance indicators (Cox, Issa and Ahrens, 2003). Qualitative KPIs present a descriptive property and characteristic of an asset in the form of a communication or report. Examples of quantitative KPIs are cost per man-hour, unit per cost, on-time completion, quality control and rework (Cox, Issa and Ahrens, 2003; Barlish and Sullivan, 2012). Quantitative KPIs are measurable characteristics through quantitative data. Examples of qualitative KPIs are motivation, safety, customer satisfaction, employee turnover and absenteeism (Cox, Issa and Ahrens, 2003; Barlish and Sullivan, 2012).

In adopting KPIs for evaluating BIM business value measurement, an organisation will have to first establish the factors it intends to measure in relation to any change or activity. That is, the organisation must gather only data that directly relates to the performance of the task in question and not to report on all data gathered from the activity. Once the KPIs have been determined. A range for project success and failure criteria will have to be set to enable accurate analysis.

One of the challenges of applying this method for measuring business value is the amount of resources required to develop performance benchmarks in owner-operator organisations. The benchmarking data for comparison has to be available for the asset manager to be able to evaluate whether targets have been met. Another weakness of using KPIs is that the models fail to identify actual parameters that represent the change in performance (Cox, Issa and Ahrens, 2003).

2.13.2.1.4 PROCESS MAPPING

Process mapping is a technique that involves identifying, documenting, analysing and developing an improved process (Anjard, 1996). It can be used to identify where improvements can be made or to compare where improvements have been made. Process mapping is a useful tool for identifying business process problems such as errors, repetitive processes, delays and inefficiencies. A process map is a visual aid that helps show how inputs, outputs and tasks are interlinked (Anjard, 1996). Process mapping as a process-based approach to evaluation that can provide organisations with a greater understanding of their business processes, thereby revealing how and why business value is created.

When applied to BIM, process mapping is mostly utilised in evaluating BIM business value in relation to process improvement or re-engineering. This evaluation is performed at the basic level of organisational processes in order to examine the impact of the subject of analysis to each individual process. Some studies suggest that process mapping provides an effective process-based approach to evaluating business value as a result of the interdependency between IT-based investments and the business processes that they support (Mende, Brecht and Österle, 1994; Mooney, Gurbaxani and Kraemer, 1995; Tallon, Kraemer and Gurbaxani, 2000). Similarly, Kiviniemi and Codinhoto (2014) utilise process mapping to conduct a comparative analysis of current state against future state of BIM-based business processes in a case study. Similarly, Soussou, Aziz and Munir (2013) identify BIM business value as a result of process improvements using process mapping techniques.

2.14 CHAPTER SUMMARY

In this chapter, a comprehensive literature review is conducted in order to provide a background on existing knowledge within the domains of on AM, BIM and business value realisation. However, the literature identifies that in order to address the socio-technical challenge of realising BIM business value in asset operations, there is a need to address knowledge gaps in the following areas:

- The lack of knowledge and understanding amongst asset owners in the development of operational information requirements for BIM-based processes.
- The lack of understanding on techniques for integrating BIM-AM systems during asset operations.
- The lack of understanding of tools and techniques for effectively managing asset data.
- The lack of understanding of key business processes that drive BIM business value during asset operations
- The lack of understanding on approaches, tools and techniques for evaluating BIM business value during asset operations.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 RESEARCH METHODOLOGY

3.1 CHAPTER INTRODUCTION

This chapter presents the methodological approach adopted for this study as well as the rationale for selected methods and strategies. The main purpose of this chapter is to develop a suitable methodology that shows a logical link between the study objectives and research outcomes. The credibility of any research work hinges on the methodology adopted for collecting and analysing data. The chapter discusses the research philosophy, approach, strategy, methods, techniques, design, time horizon and ethical considerations. Furthermore, as previously identified, the research problem is socio-technical in nature. As such, the research methods laid out in this chapter have been carefully selected to suit the nature of the research problem. Furthermore, in order to describe the components of research methodology, this study adopts the '*Research Onion'* proposed by Saunders, Lewis and Thornhill (2016). The rationale for selecting this framework lies in its potential to assist the researcher in achieving the study's aim and objectives in the most efficient and effective manner. The '*Research Onion*' helps the researcher to systematise the knowledge espoused in the course of the research by investigating the technical (BIM-AM systems) and social (organisational or management) problems identified in this study. The framework helped to define and explore concepts within BIM and AM systems (technical) implementation as well as management and value realisation approaches during asset operations. The '*Research Onion'* method enabled the researcher to plan and make decisions about research tactics, which are about the finer details and underlying choices of data collection and analysis (Saunders, Lewis and Thornhill, 2016). The utilisation of this framework aided the researcher in charting the course for the selected research philosophy, approach, strategy and technique during the course of the study. These areas are represented in layers in Figure 3.1. The following sections and sub-sections will discuss each element of the '*Research Onion*' in further detail. This chapter is organised in this order in order to ease the discussion.

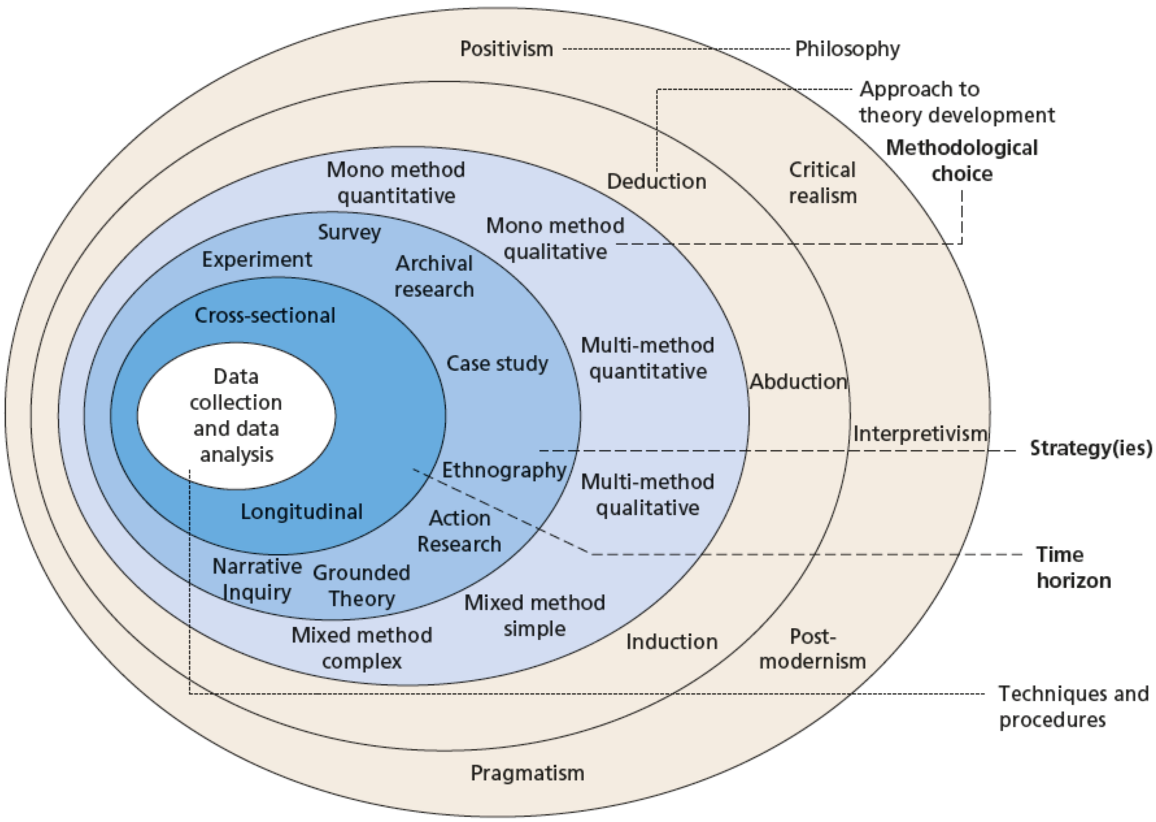


Figure 3.1: Research progression (Research Onion) (Saunders, Lewis and Thornhill, 2016)

3.2 RESEARCH METHODS

Research methods refer to the set of concepts that form a structured framework through statements of relationships for achieving the research objectives and explaining or predicting phenomena. The aim of this research is to develop a model that will guide asset owners in deriving BIM business value during asset operations in an AM system. In developing a theory, the evolving theory should be the driving force of the research, and the research methods should represent the means to achieving that end (Creswell, 2003). Saunders, Lewis and Thornhill (2016) suggest the methodological progression of a research in six categories; philosophy, approach, strategy, methodological choice, technique and time horizon. These are used to guide the answering of the research questions and achieving the research objectives. Although, the framework highlights a number of research methods, this study only discusses the selected methods and their rationale.

3.2.1 RESEARCH PHILOSOPHY

Research philosophy refers to the belief about how data regarding a phenomenon is gathered, analysed and used. Generally, philosophy concerns the idea of different views of the world, how reality is perceived, how knowledge is gained and the processes within it (Saunders, Lewis and Thornhill, 2016). The research methodology of any study relies on the philosophical grounding of ontological and epistemological concepts (Flick, 2019). Ontology refers to the nature of reality and epistemology represents how knowledge is obtained and the relationship between the researcher and the subject of study within the context of the research (Creswell, 2003; Saunders, Lewis and Thornhill, 2016). A credible research philosophy based on consistent assumptions will determine a suitable research strategy, approach, methodological choice, data collection and analysis (Saunders, Lewis and Thornhill, 2016). A credible research philosophy refers to a well thought out and consistent set of assumptions that underpin the research strategy, methodological choice and data collection techniques and analysis procedures. As such, this produces a coherent research project, in which all aspects of research fit together as presented in this chapter.

This study can be examined from two philosophical positions, which are the research ontology and epistemology. The ontological and epistemological stance of this study is relativism and constructivism (interpretivism) respectively (Creswell, 2003; Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). This study employed the interpretivist or constructivist paradigm to analyse and interpret research data that guided the development of a framework that would guide asset managers to derive BIM business value in asset operations. The relativist research paradigm viewed the research phenomenon, whilst acknowledging that there is no objective reality but merely a number of subjective truths about BIM business value in asset operations. This relativist approach of seeking to answer how asset owners can realise BIM business value in an AM system in the lifecycle of a built asset; whilst acknowledging that BIM business value is not absolute; and that asset owners are not a homogenous group of organisations, as such, do not apply the same technology, approach and/or standards; is the subjective view. Consequently, this highlights the ontological nature of the primary research question in this study. Interpretivism is suitable for studies that aim to investigate phenomena in a real-world environment through subjective interpretation in order to understand and reveal behaviour in relation to the phenomena (Mason, 2014). As such, this study focuses on the real-world subjective interpretation of BIM business value in AM from the perspective of asset owners. An interpretivist or constructivist approach presumes that there exist multiple realities that are constructed by the researcher based on meanings and interactions within the research context of BIM business value in AM (Saunders, Lewis and Thornhill, 2016). Similarly, the interpretivist paradigm guides the selection of an appropriate research methodology in investigating BIM business value for asset owners. The interpretivist paradigm is suitable for this study because it assumes that the phenomenon of study is by no means independent of the researcher, as is the case in this study. The interpretivist view is suitable for this study because it assumes: that knowledge is established through the meanings attached to the phenomena studied, which is BIM business value; researchers interact with the subjects of study to obtain data, which are asset owners or managers; and knowledge is context and time-dependent, which is the nature and type of asset owner (Krauss, 2005).

3.2.2 RESEARCH APPROACH

Saunders, Lewis and Thornhill (2016) highlight the extent to which the researcher needs to be clear about the study research questions and in selecting a suitable research approach to theory development. There is a need to consider the study research questions from three aspects; theory building, theory validation and theory development (Creswell, 2003; Yin, 2003). These perspectives guide the researcher in selecting an appropriate research approach to be utilised in answering the study's research questions. There are three types of philosophical reasoning; induction, deduction and abduction (Proctor and Capaldi, 2006; Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Inductive reasoning concerns theory building and deductive reasoning represents theory testing (Saunders, Lewis and Thornhill, 2016). However, abductive reasoning is a combination of both induction and deduction (Saunders, Lewis and Thornhill, 2016).

This study adopts an abductive research approach to develop a BIMAsset Value Realisation Model (BIMAsset VRM) that will assist asset owners in deriving BIM business value in asset operations.

Abductive reasoning refers to the research approach of studying phenomena and developing a theory or framework that explains or addresses them (Cunningham, 1998). It is concerned with developing theories and explaining the facts of a phenomenon that is justifiably better than alternative theories (Proctor and Capaldi, 2006). Saunders, Lewis and Thornhill (2016) suggest that it is often advantageous to use an abductive approach, which is to combine both induction and deduction within the same piece of research. Cunningham (1998) argues that abductive reasoning is a suitable method for understanding new or unknown situations. Similarly, Robson and McCartan (2016) assert that abductive reasoning is well suited for generating useful theories, models or frameworks in a real-world context.

In most cases, theoretical statements of science are arrived at abductively (Proctor and Capaldi, 2006). There are three types of abductive reasoning: explaining inference in data; entertaining multiple hypotheses; and inference to the best explanation (Proctor and Capaldi, 2006). The study applies explaining inference in data (SRQ-1, SRQ-2, SRQ-3 and SRQ-4) and inference to the best explanation (PRQ and SRQ-5) in order to achieve the research objectives. Explaining inference in data refer to the evaluation of a phenomenon and deriving specific predictions. This means that if the generalisation is true, then the world is as observed by the researcher (Robson and McCartan, 2016). On the other hand, inference to the best explanation refers to the development and acceptance of a model or framework that provides the best possible explanation of available facts of a phenomenon under study (Holcomb, 1998).

This thesis comprises of five studies (Chapters 4 – 8). The research questions and study objectives are addressed in different chapters of the thesis through an abductive research approach. Strauss and Corbin (1998) suggest that it is normal to present a research project in a series of smaller investigations, with each study building on the results of previous studies before being integrated into a whole. Chapter 8 addresses the PRQ and SRQ-5; (ii) Chapter 4 addresses SRQ-1; (iii) Chapter 5 addresses SRQ-2; (iv) Chapter 6 addresses SRQ-3; and (iv) Chapter 7 addresses SRQ-4. Furthermore, it is worth noting that deduction is not only confined to inferences based on premises that are absolutely true (Quantitative and Experimental Studies) but is also used to make implications from premises that are only empirically (and therefore probably) true (Qualitative studies) (Shank, 2008).

3.3 RESEARCH STRATEGY

Saunders, Lewis and Thornhill (2016) suggest eight research strategies, and they are; experiment, survey, case study, archival research, ethnography, action research, grounded theory and narrative enquiry. Through abductive reasoning, this study adopts case study and archival research strategies to answer the research questions and achieve the study's objectives. In this study, the case study as a research strategy is used to contribute to knowledge and understanding of individual, organisational and social-related phenomena (Yin, 2003). In AEC research, case studies can be used: (a) to describe phenomena; (b) as a source of insights and ideas; (c) as illustrative anecdotes; and (d) as project-biography (Fellows and Liu, 2015). Case studies are useful in understanding complex social phenomena, and they allow the investigation of holistic and meaningful characteristics of real-life events such as BIM business value in AM, which is the core focus of this study. Also, case studies enable in-depth investigations of a particular phenomenon that is representative of general cases (Fellows and Liu, 2015). The case study research strategy can be said to be flexible to many research philosophies, approaches and techniques. It can be single or multiple; it can be carried out with an interpretivist philosophy; it can take on an inductive, deductive or abductive approach; and it can use qualitative or quantitative research techniques (Cavaye, 1996). A multi-case study approach allows a researcher to analyse data from different perspectives to produce more robust evidence that could be generalisable (Creswell, 2003; Yin, 2003). However, a multi-case study strategy is adopted for answering SRQ-1 and SRQ-4 (Chapters 4 and 7). Case studies are suitable for '*how*', '*what*' and '*why*' type research questions (Yin, 2003). The profile for all the cases engaged in this study are shown in Table 3.1.

Table 3.1: Research case study profile

S/NO	INDUSTRY ACTOR	COUNTRY	INDUSTRY SECTOR	YEAR OF STUDY
1	Client/Owner	UK	Retail	2017
2	Consultant	UK	Consultant Retail	2017
3	Client/Owner Consultant	Finland	Building Services MEP	2018
4	Client/Owner	Finland	Government-Mixed Use	2018
5	Client/Owner	US	Health	2018
6	Client/Owner	Denmark	Education	2018

Furthermore, the connection of the case study strategy in relation to the research objectives is shown in Table 3.2.

Archival analysis as a research strategy is utilised within the context of this study to make use of administrative documents and records as one of the principal sources of data (Saunders, Lewis and Thornhill, 2016). These refer to a range of organisational documents such as EIR templates, AM protocols, BIM implementation strategic papers, change management procedures and value realisation management strategies. The researcher utilised archival analysis to analyse documents sourced from fieldwork activities for data analysis. A document may be in the form of text, visual or audio representations (Taylor, Bogdan and DeValut, 2016; Saunders, Lewis and Thornhill, 2016). Archival analysis is useful in understanding and analysing specific social phenomena within institutions (Taylor, Bogdan and DeValut, 2016). Furthermore, this study acknowledges the need for sensitivity on the initial purpose of documentary sources prior to utilising them for data analysis (Saunders, Lewis and Thornhill, 2016). It is normal to combine archival analysis alongside a case study strategy based on qualitative methods (Fellows and Liu, 2015; Saunders, Lewis and Thornhill, 2016). Archival analysis is suitable for '*how many*', '*what*' and '*where*' type research questions (Yin, 2003). The connection of the archival analysis strategy to the research objectives is shown in Table 3.2.

Furthermore, the nature or purpose of any study would determine the research strategy to be adopted. The nature of any study may be exploratory, descriptive, explanatory or evaluative (Saunders, Lewis and Thornhill, 2016). The study utilised a combination of exploratory and descriptive. An exploratory study is used to gain insights in order to clarify the understanding of a phenomenon, which is BIM business value in AM (Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Descriptive studies are aimed at gaining accurate profiles of the phenomenon of BIM-based AM in relation to business value realisation management (Saunders, Lewis and Thornhill, 2016). An exploratory study is suitable for answering '*wha*t' type research questions (Yin, 2003). Similarly, a descriptive study is suitable for answering '*what*' and '*how*' type research questions (Creswell, 2003; Robson and McCartan, 2016).

This study utilised a combination of case study and archival analysis strategies in Chapters 4, 5, 6 and 7. In Chapter 8, the outcomes of Chapters 4, 5, 6 and 7 are used to generate the BIMAsset VRM. However, Chapters 4 and 7 utilised a multi-case study strategy approach. Chapters 4, 5, 6, 7 and 8 are exploratory and descriptive in nature. The critical aspect of this study is to understand the factors that hinder BIM business value in AM. In order to understand these factors, exploratory studies need to be carried out. First, to explore in order to understand the processes of developing operational information requirements in AM; how BIM and AM systems as set-up; how asset data is effectively managed; what are the key business processes that drive BIM business value in AM; and what are the techniques of measuring BIM business value in AM. It can be seen from this line of inquiry that there is a reflection of the interrelationship between social (AM business processes) and technical (BIM-AM) systems. As mentioned earlier, the case study and archival research strategies are used to answer these lines of inquiry. These strategies are appropriate for addressing the primary research question posed because the answers sought operational links, methods and approaches rather than frequencies or incidence (Yin, 2003). Furthermore, they require the investigator to rely on primary documents, secondary documents and interviews of the persons involved in the events. Second, the elements and sub-elements of the proposed model are established through analysis and conceptualisation of the collected data from the case study and archival research strategies.

Furthermore, the research objectives and questions for the study were developed to address the identified factors that hinder BIM business value realisation by asset owners (identified in Section 1.5); they are:

- The lack of clear definition of information requirements for BIM-based processes by asset owners.
- The inadequate level of understanding of asset owners on the techniques for setting-up BIM and AM systems to work efficiently during asset operations.
- The lack of awareness of tools and techniques for digitally managing asset data.
- The lack of awareness by asset owners on key business processes that drive BIM business value during asset operations.
- The insufficient understanding by asset owners of approaches, tools and techniques for evaluating BIM business value during asset operations.

Table 3.2 shows the research strategies adopted in relation to the study's research questions.

Table 3.2: Shows the research strategy and nature paired against each research question

NOTATION	RESEARCH QUESTIONS	STRATEGY	NATURE	CHAPTER
SRQ-1	What are the important and common information requirements for AM processes and how these requirements relate to BIM?	Case Study Archival Analysis	Exploratory Descriptive	4
SRQ-2	What are the techniques and strategies of streamlining AM systems for BIM-based integration, and what information should be captured from physical assets towards BIM-based integration?	Case Study Archival Analysis	Exploratory Descriptive	5
SRQ-3	How does the information content captured from physical assets generate business value in AM, and which aspects relate to BIM?	Case Study Archival Analysis	Exploratory Descriptive	6
SRQ-4	What are the vital AM business processes that drive BIM business value, and how do they relate to business process maturity?	Multi-Case Study Archival Analysis	Exploratory Descriptive	7
SRQ-5	What are the techniques and strategies of measuring the business value of BIM in AM processes, and how can intangible value be linked to tangible value?	Archival Analysis (Secondary Data)	Exploratory	8
PRQ	How can the BIMAsset Value Realisation Model support asset managers in deriving BIM business value?	Multi-Case Study Archival Analysis	Exploratory Descriptive	8

3.4 METHODOLOGICAL CHOICES

Saunders, Lewis and Thornhill (2016) suggest six methodological choices when conducting a research, and they are; mono-method quantitative, mono-method qualitative, multi-method quantitative, multi-method qualitative, mixed-method simple and mixed-method complex. Through abductive reasoning, this study adopts multi-method qualitative research to answer the research questions and achieve the study's objectives. The study adopts more than one qualitative method to collect and analyse data.

Qualitative methods have unique steps in data collection and analysis, which rely on text and image data and can draw on diverse designs (Creswell, 2003). Qualitative methods seek to gain insights by eliciting information on people's experience, feelings and priorities (Fellows and Liu, 2015). Unlike quantitative research, qualitative research does not concern testing relationships about dependent and independent variables (Saunders, Lewis and Thornhill, 2016). Qualitative research is often associated with an inductive, deductive or abductive logic of enquiry (Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Similarly, qualitative research is usually associated with an interpretivist philosophy because the researcher needs to make subjective and socially constructed conclusions about the phenomenon being studied (Saunders, Lewis and Thornhill, 2016). Research questions in qualitative research are statements that identify and state specifically what the researcher seeks to find within the subject area (Creswell, 2003). Qualitative research is suitable for '*what*', '*where*', '*how*' and '*why*' type research questions (Robson and McCartan, 2016). A qualitative method is employed in this study because: (a) the concept is undeveloped due to a conspicuous lack of value realisation models and previous research; and (b) the need to explore and describe the phenomena of BIM business value in AM and to develop a framework to address the research problem (Creswell, 2003) (Rationale discussed in Section 1.4). Table 3.3 shows the research strategies adopted in relation to the study objectives and research questions.

Table 3.3: Shows the methodological choices paired against each research objective and research question

S/NO	RESEARCH OBJECTIVE	NOTATION	RESEARCH QUESTION	METHODS
1	To identify the key operational information requirements in AM business processes and how they relate to BIM.	SRQ-1	What are the important and common information requirements for AM processes, and how do these requirements relate to BIM?	Qualitative
2	To investigate and identify the strategies and techniques of how asset owners can integrate BIM with AM systems and the business value to be derived from such integration.	SRQ-2	What are the techniques and strategies of streamlining AM systems for BIM-based integration, and what information should be captured from physical assets towards BIM-based integration?	Qualitative
3	To investigate how the information content collected from built assets generate business value in a BIM-based AInfM system, including key techniques of managing asset data and how that data is reported for critical decision-making.	SRQ-3	How does the information content captured from physical assets generate business value in AM, and which aspects relate to BIM?	Qualitative
4	To investigate, identify and evaluate activity systems that drive BIM business value in AM.	SRQ-4	What are the vital AM business processes that drive BIM business value, and how do they relate to business process maturity?	Qualitative
5	To investigate the techniques and strategies of measuring the business value of BIM in AM processes and how intangible value can be measured.	SRQ-5	What are the techniques and strategies of measuring the business value of BIM in AM processes, and how can intangible value be linked to tangible value?	Qualitative
6	To develop a model for business value realisation of BIM implementation in the lifecycle management of assets for clients.	PRQ	How can the BIMAsset Value Realisation Model support asset managers in deriving BIM business value?	Qualitative

3.5 RESEARCH TECHNIQUE

Techniques and procedures are the tools used to acquire research data for analysis (Saunders, Lewis and Thornhill, 2016). Generally, qualitative findings emanate from three types of data collection approaches; interview, observation and document analysis (Patton, 2002; Creswell, 2003). The qualitative techniques utilised for this study are semi-structured interviews, document analysis, group interviews (focus groups) and literature review. Furthermore, Fellows and Liu (2015) suggest a further classification of one-way and two-way communications in data collection. One-way communications include completely structured and unstructured interviews, archives (documents) and observations. Two-way communications include semi-structured interviews and participant observation. One-way approaches are linear and focus on transferring data or information, whilst two-way methods permit feedback and are more suitable in transferring meaning (Fellows and Liu, 2015). This study adopts both one-way and two-way communication methods in data collection in the form of semi-structured interviews, document analysis, group interviews (focus groups) and literature review. There are two types of data; primary and secondary. Primary data refers to new data collected for the purpose of the research, and secondary data means data (raw or published) collected initially for some other purpose (Saunders, Lewis and Thornhill, 2016). This study utilises primary data in the form of case study semi-structured interviews and focus group interviews. Secondary data in the form of organisational archival records, textbooks, journals, conference proceedings, reports and websites are utilised for the conduct of this research. Table 3.4 shows the relationship between research questions and research techniques employed during the course of the research.

Table 3.4: Shows the research technique paired against each research question

NOTATION	RESEARCH QUESTION	TECHNIQUE
SRQ-1	What are the important and common information requirements for AM processes and how these requirements relate to BIM?	Interviews
		Document Analysis
SRQ-2	What are the techniques and strategies of streamlining AM systems for BIM-based integration, and what information should be captured from physical assets towards BIM-based integration?	Interviews
		Document Analysis
SRQ-3	How does the information content captured from physical assets generate business value in AM, and which aspects relate to BIM?	Interviews
		Document Analysis
SRQ-4	What are the vital AM business processes that drive BIM business value, and how do they relate to business process maturity?	Interviews
		Document Analysis
SRQ-5	What are the techniques and strategies of measuring the business value of BIM in AM processes, and how can intangible value be linked to tangible value?	Document Analysis (Secondary Data)
PRQ	How can the BIMAsset Value Realisation Model support asset managers in deriving BIM business value?	Interviews
		Document Analysis
		Focus Group

3.5.1 SEMI-STRUCTURED INTERVIEWS

A semi-structured interview is the activity of collecting data by asking questions and recording responses of participants with the scope of probing further by asking supplementary questions in order to obtain more details and pursue new interesting aspects (Fellows and Liu, 2015). There are three types of interviews; structured, semi-structured and in-depth interviews (Fellows and Liu, 2015; Saunders, Lewis and Thornhill, 2016). Semi-structured interviews are advantageous for gathering and analysing qualitative data and are well suited for case study and grounded theory research strategies (Proctor and Capaldi, 2006; Saunders, Lewis and Thornhill, 2016). Also, semi-structured interviews are appropriate for exploratory, descriptive and explanatory studies (Saunders, Lewis and Thornhill, 2016). Semi-structured interviews are beneficial when adopting an interpretivist philosophy because it allows the researcher to probe answers in aspects where there is a need for respondents to explain and build on responses (Saunders, Lewis and Thornhill, 2016). For the conduct of this study, the technique of semi-structured interviews is central to understanding the meanings which participants ascribe to different aspects of the phenomena of BIM-based AM in relation to value realisation management.

For the systematic collection of data during this study, the technique of semi-structured interviews is utilised. These interviews allowed the researcher some control over responses, whilst allowing respondents the freedom to express their views on the subject under study. Semi-structured interviews are utilised because the questions are complex, and some aspects were open-ended (Saunders, Lewis and Thornhill, 2016). Furthermore, Saunders, Lewis and Thornhill (2016) suggest different forms of interview, and they are; interview administered questionnaires, face-to-face, telephone and internet-mediated interviews. This study conducted eleven face-to-face interviews, one telephone interview and four internet-mediated interviews.

The interview questions are developed from a systematic method of thematic analysis for each study (Boyatzis, 1998). The interview questions in this thesis are based on a list of themes, study by study and respondent basis (Saunders, Lewis and Thornhill, 2016). The interview questions utilised for this study are attached in Appendix B. For SRQ-1 to SRQ-4, semi-structured interviews are conducted. Criteria for the selection of respondents is expressed in Sections 4.3.3, 5.3.3, 6.3.3 and 7.3.3 of this study. These respondents represent clients (asset owners) and consultants. The interviews took place in 2017 and 2018. Each interview was audio-recorded and lasted an average of 65 minutes. Some of the interviews are conducted in pairs for participants that work together when investigating a particular phenomenon. Table 3.5 shows the profile of respondents engaged during the period of the study.

Table 3.5: Research interview profile

S/NO	INDUSTRY ACTOR	JOB DESCRIPTION	COUNTRY	MEDIUM	DATE	MINUTES
1	A. Client/Owner B. Consultant	A. Director Digital Services B. Associate Director	UK	Face-to-face	14.11.2017	120
2	Consultant	Associate Director	UK	Face-to-face	01.12.2017	60
3	Consultant	Associate Director	UK	Face-to-face	16.02.2018	60
4	Client/Owner	Projects and Innovation Manager	UK	Telephone	13.02.2018	60
5	A. Consultant B. Consultant	A. Director Manager Services B. Technology Director I	Finland	Face-to-face	28.05.2018	60
6	Consultant	Senior Technology Consultant	Finland	Face-to-face	28.05.2018	90
7	Consultant	Technology Director II	Finland	Face-to-face	29.05.2018	60
8	A. Consultant B. Consultant	A. Software Development Manager Services B. Technology Director I	Finland	Face-to-face	29.05.2018	60
9	Consultant	Development Manager	Finland	Face-to-face	29.05.2018	60
10	Consultant	Technology Director I	Finland	Face-to-face	29.05.2018	60
11	Consultant	Business Director Digital Real Estate	Finland	Face-to-face	30.05.2018	60
12	Client/Owner	Director Facility Maintenance Digitalization	Finland	Face-to-face	31.05.2018	60
13	Client/Owner	Director Facilities Management	US	Internet Mediated	30.05. 2018	60
14	Client/Owner	Director Facilities Management	US	Internet Mediated	10.09.2018	60
15	Client/Owner	Head of Digital Campus Service	Denmark	Internet Mediated	08.10.2018	60
16	Client/Owner	Head of Digital Campus Service	Denmark	Internet Mediated	09.10.2018	60

3.5.2 DOCUMENT ANALYSIS

Document analysis refers to the sourcing and use of records, artefacts and archives for analysis when conducting research (Patton, 2002). In case study research, interview data is usually accompanied with documentary (archival) data (Fellows and Liu, 2015). Similarly, Creswell (2003) opined that it is normal for the researcher to request for and collect documents during interviews. Collection of archival data for analysis is well suited for the case study and archival strategies (Patton, 2002; Fellows and Liu, 2015). As part of the data collection exercise, the researcher collected qualitative documents that relate to the phenomena of BIM-Based AM and value realisation management. During archival analysis, the technique of content analysis is used to investigate a phenomenon within the subject area. One of the benefits of using content analysis is that it allows the researcher to test theoretical issues and, in turn, gives the researcher a better understanding of the collected data.

3.5.3 FOCUS GROUP

Focus groups are interviews that take place in a group context with the researcher as a moderator (Fellows and Liu, 2015). They can be structured, semi-structured and unstructured (Fellows and Liu, 2015; Robson and McCartan, 2016). This study adopts the semi-structured format of the focus group as an expert panel for validating the research outcome, which is the BIMAsset VRM (Fischer, 2006). The focus groups check the model for fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency (Proctor and Capaldi, 2006). The nature of the interview involved a crossbreed of a group discussion and an interview session in responding to the aforementioned criteria in order to validate the BIMAsset VRM (Robson and McCartan, 2016).

The study conducts this activity through the careful selection of an expert panel due to their knowledge of the utilisation of BIM in asset operations. The focus group comprised of six professionals. The results of the research are presented to the expert panel to solicit for an external opinion on the research methods and outcome. The purpose of this exercise is to validate whether the research area has been properly covered. During the focus group, the researcher presents the BIMAsset VRM and how it improves knowledge of the concept of BIM-based AM and value realisation. The focus group was asked to predict solutions to the problem, and the research outcome is used as possible solutions to the problem. The two predictions were both compared. Also, feedback on other aspects of the BIMAsset VRM is used to refine the model further. The results of the focus group are presented in Chapter 10 of this study.

3.5.4 SAMPLING TECHNIQUES

There are two types of sampling; probability and non-probability (Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Probabilistic sampling involves the use of a random sample to ensure generalisability, while non-probabilistic sampling involves selecting a sample purposefully (Saunders, Lewis and Thornhill, 2016). This study adopts non-probabilistic or purposeful sampling during data collection. This is because qualitative inquiries focus in-depth on relatively small samples selected purposefully (Patton, 2002). Purposeful sampling is appropriate for studies where the research question does not indicate any form of sample, and the researcher collects data from a sample that is readily available (Fellows and Liu, 2015). Similarly, Eisenhardt (1989) posits that random sampling is neither necessary nor preferable in model development, considering that there is a limit to the number of cases that can be studied in any research project. Furthermore, Saunders, Lewis and Thornhill (2016) highlight that in a qualitative enquiry, collecting data from fewer cases can be advantageous because the researcher can obtain very detailed study data. The sample size for this study is shown in Table 3.1. Furthermore, this study adopts two types of non-probability sampling in case and participant selection, and they are; theory-based sampling and snowballing (Patton, 2002). The study utilised operational construct and theoretical sampling as types of theory-based sampling. The cases and respondents are selected purposefully based on their experience and knowledge of BIM utilisation in AM, and their profile is shown in Table 3.6.

Table 3.6: Respondent profile

S/NO	INDUSTRY ACTOR	JOB DESCRIPTION	EXPERIENCE IN BIM (YEARS)	EXPERIENCE IN AM (YEARS)	EXPERIENCE IN BIM IN AM (YEARS)
1	Client/Owner	Director Digital Estates Services	6	11	4
2	Consultant	Associate Director	25	10	10
3	Client/Owner	Projects and Innovation Manager	5	10	5
4	Consultant	Director Manager Services	14	14	14
5	Consultant	Senior Technology Consultant	5	20	5
6	Consultant	Technology Director I	20	15	5
7	Consultant	Technology Director II	10	5	5
8	Consultant	Software Development Manager Services	10	10	2
9	Consultant	Development Manager	14	14	14
10	Consultant	Business Director Digital Real Estate	5	5	5
11	Client/Owner	Director Facility Maintenance Digitalization	15	15	5
12	Client/Owner	Director Facilities Management	14	11	11
13	Client/Owner	Head of Digital Campus Service	8	5	5

Operational construct is a non-probability sampling strategy for qualitative research in studying real-world examples and for investigating phenomena through a real-life design (Patton, 2002). The purpose of utilising this strategy is to select cases that represent real-world operational representations of BIM utilisation in asset operations. Operational construct sampling is suitable for investigations where the sample population of BIM adopters in AM is not known, thereby making random sampling impracticable (Patton, 2002). This study selected cases that are representative of real-world examples in order to research on BIM business value for clients in an AM system.

Snowballing is a non-random method of obtaining samples that are difficult to access usually because individual sources of data cannot be readily identified (Patton, 2002; Fellows and Liu, 2015; Robson and McCartan, 2016). This technique relies on sources which are referred to as seeds that will provide links to identify the next respondents, thereby building a progressively sufficient sample (Fellows and Liu, 2015; Robson and McCartan, 2016). This technique is adopted because of the limited application of BIM in AM in the AEC industry as a result of the challenges identified in Section 1.3. The study utilised this strategy to explore professional networks in order to gain access to research data. The snowballing technique is suitable for case study and archival research techniques (Taylor, Bogdan and DeValut, 2016).

3.5.4.1 SELECTION CRITERIA FOR EACH CASE

There is no consensus in the number of cases to sample in a multi-case study research; as such, this number should be guided by the replication of logic that depends on what new information can be collected by increasing the number of cases (Saunders, Lewis and Thornhill, 2016). The case studies in this research are selected by the researcher. The case studies selected for the multi-case study chapters due to the expectation of literal replication (Yin, 2003). The rationale for selecting case studies are: (i) The sampled asset owners are experienced users of BIM; (ii) The selected case studies are utilising BIM in asset operations; (iii) The selected cases are exhibiting appropriate characteristics of BIM business value realisation; (iv) The organisations were willing to give access to data for the study. The six case studies were selected from four countries: UK, US, Finland and Denmark. These are countries that have advanced levels of BIM implementation. Furthermore, there are no contextual implications for the data collected, since the study is not limited to investigating phenomena in a single country, and the use of BIM in asset operations are similar globally in terms of the socio-technical nature (with only major differences in national standards). Also, organisations are increasingly seeking and applying approaches from international best practices, and not only BIM projects or case studies that are domiciled in their countries. An example is the utilisation of case study material from the Sydney Opera House by asset owners (Kivits and Furneaux, 2013). As such, the study sample was not limited to geographical boundaries and the contextual implications data collected are considered to be insignificant.

3.5.5 DATA ANALYSIS

Data analysis refers to the interaction between the researcher and study data. It is the science of maintaining a certain level of rigour in data analysis and creativity through the development of themes, categories, comparisons and interpretations to produce a realistic scheme of information from unorganised raw research data (Strauss and Corbin, 1998). This study utilised mixed methods in data analysis. Mostly, qualitative data analysis is utilised in analysing semi-structured interviews, documented data and focus group interviews. Quantitative data is partially used in analysing documented data in Chapter 4 and semi-structured interviews in Chapter 7. This is because some aspects of the qualitative research data required systematic and standardised comparisons using quantitative descriptive statistics in order to graphically present the study data (Saunders, Lewis and Thornhill, 2016). The quantitative descriptive statistics technique utilised in this study is the measure of frequency though bar charts (Chapter 4), stacked bar charts (Chapter 4) and radar charts (Chapter 7). These charts are generated using Microsoft Excel™ software (Walkenbach, 2015).

In analysing qualitative data, the NVivo™ software was used to transcribe and analyse the primary data (Bazeley and Jackson, 2013; Saunders, Lewis and Thornhill, 2016). This study utilised coding for easy analysis, indexing and retrieval of primary data (Boyatzis, 1998). Here, two qualitative data analysis techniques are utilised; they are: thematic analysis and content analysis (Boyatzis, 1998; Krippendorff, 2013).

Thematic analysis is a research technique of encoding qualitative information, which requires an explicit code in the form of themes (Boyatzis, 1998). A theme is a subject matter that is identified in the raw study data in order to describe and categorise potential observations at the minimum or to interpret characteristics of a phenomenon at the maximum. The process of thematic analysis may be in the form of indicators, list of themes, a complex model comprising themes, qualifications with causal relationships or something in between these descriptions (Boyatzis, 1998). On the other hand, content analysis is a research technique for analysing visual, verbal or written communication messages (Krippendorff, 2013). It allows researchers to easily sort data in a systematic fashion in order to make inferences that can complement other methods of data collection. Content analysis is useful in identifying trends and specific subject matters in relation to the research problem in documents (Krippendorff, 2013).

Furthermore, to achieve the data analysis activities of thematic analysis and content analysis, the following set of functions are conducted using the NVivo™ software; word frequency query, text search query, and coding query (Bazeley and Jackson, 2013; Saunders, Lewis and Thornhill, 2016). Word frequency query is utilised to visualise and identify topical issues in terms of word frequency (Bazeley and Jackson, 2013). This function enabled data examination during content analysis. To build upon the existing analysis, the text search query function provided a word tree relationship that is utilised to identify specific issues by selecting keywords or phrases in order to visualise how it is used in different contexts (Bazeley and Jackson, 2013). This feature aided thematic analysis through the evaluation of relationships of keywords identified from the word frequency query. Coding query is utilised to sort and filter analysed data based on how it is coded (Bazeley and Jackson, 2013). This function helped the researcher to analyse data based on classifications of observed phenomena during thematic analysis and content analysis (Bazeley and Jackson, 2013).

Further details of how these techniques were applied in individual studies are expressed in Sections 4.3.4, 5.3.1.2, 6.3.1.2 and 7.3.1.3 of this thesis. Figure 3.3 shows the steps followed by the researcher during data analysis.

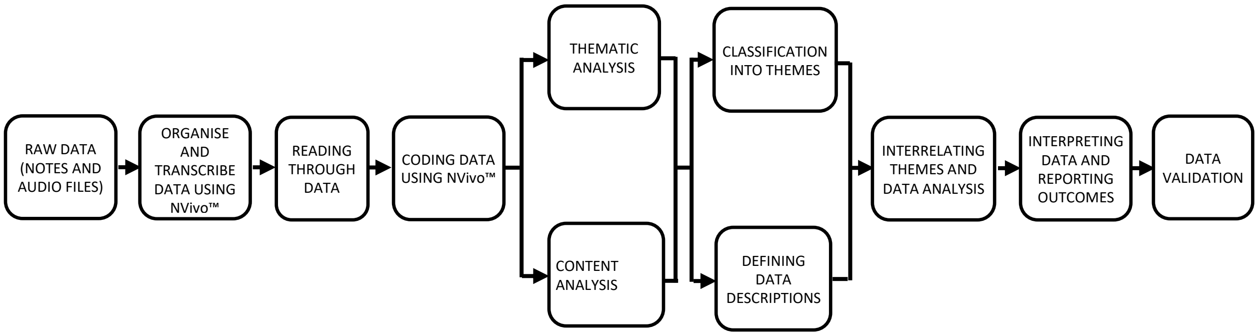


Figure 3.2: Data analysis process

3.6 TIME HORIZON

Saunders, Lewis and Thornhill (2016) highlight the need for establishing a time horizon when conducting research. This can be a cross-sectional or longitudinal time horizon. Payne and Payne (2004) define cross-sectional studies as research designs where data collection takes place at one point in time, whilst in longitudinal studies, data is continuously collected at predetermined intervals over time. Cross-sectional studies may employ case study strategies, qualitative research methods and semi-structured interview data collection techniques (Saunders, Lewis and Thornhill, 2016). Since doctoral research is time-bound, the time horizon for this study is cross-sectional. Table 3.1 shows the dates in which data were collected in a cross-sectional time horizon and not a series of snapshots taken over a long period of time (Creswell, 2003).

3.7 RESEARCH DESIGN

This study adopts the eight-step Center for Integrated Facility Engineering (CIFE) '*horseshoe*' method (Kunz and Fischer, 2007). This method works well to formalise new knowledge in the AEC industry in circumstances where it is difficult to replicate situations found in practice. Here, the project site and organisational workplace becomes the prima facie location for conducting scientific investigations (Fischer, 2006). The application of the CIFE '*horseshoe*' is useful in cases where formal design methods are difficult to apply in order to isolate particular factors when studying project or organisational outcomes. In the context of this study, the CIFE '*horseshoe*' research design helped investigate the phenomenon of BIM value realisation management in AM business processes. The study adopts a multi-case study strategy that enabled the investigation of the phenomena within the workplace of six large asset owners.

The CIFE '*horseshoe*' method is a repetitive method where research processes are constantly reviewed to ensure correlation and consistency between the research plan and research outcome (Kunz and Fischer, 2007). The correlation is shown in Figure 3.4. The CIFE '*horseshoe*' workflow helps the researcher to develop a manageable and executable research plan that is scientifically defensible and will lead to relevant results (Fischer, 2006). Hence, the justification for adopting this work plan. Furthermore, the research flow based on the research tasks carried out are shown in Figure 3.5.

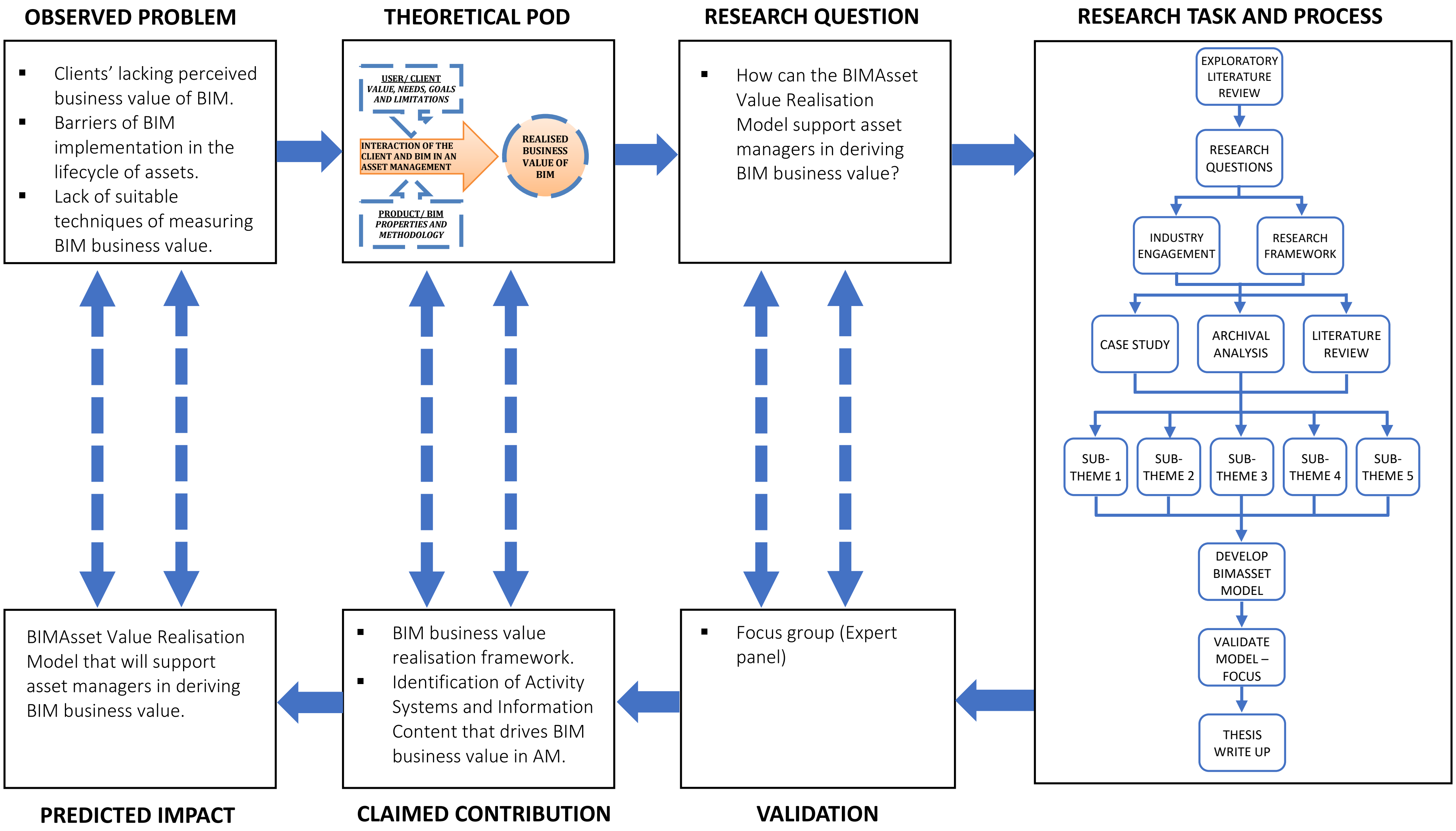


Figure 3.3: CIFE *horseshoe* research method – adapted from Kunz and Fischer (2007)

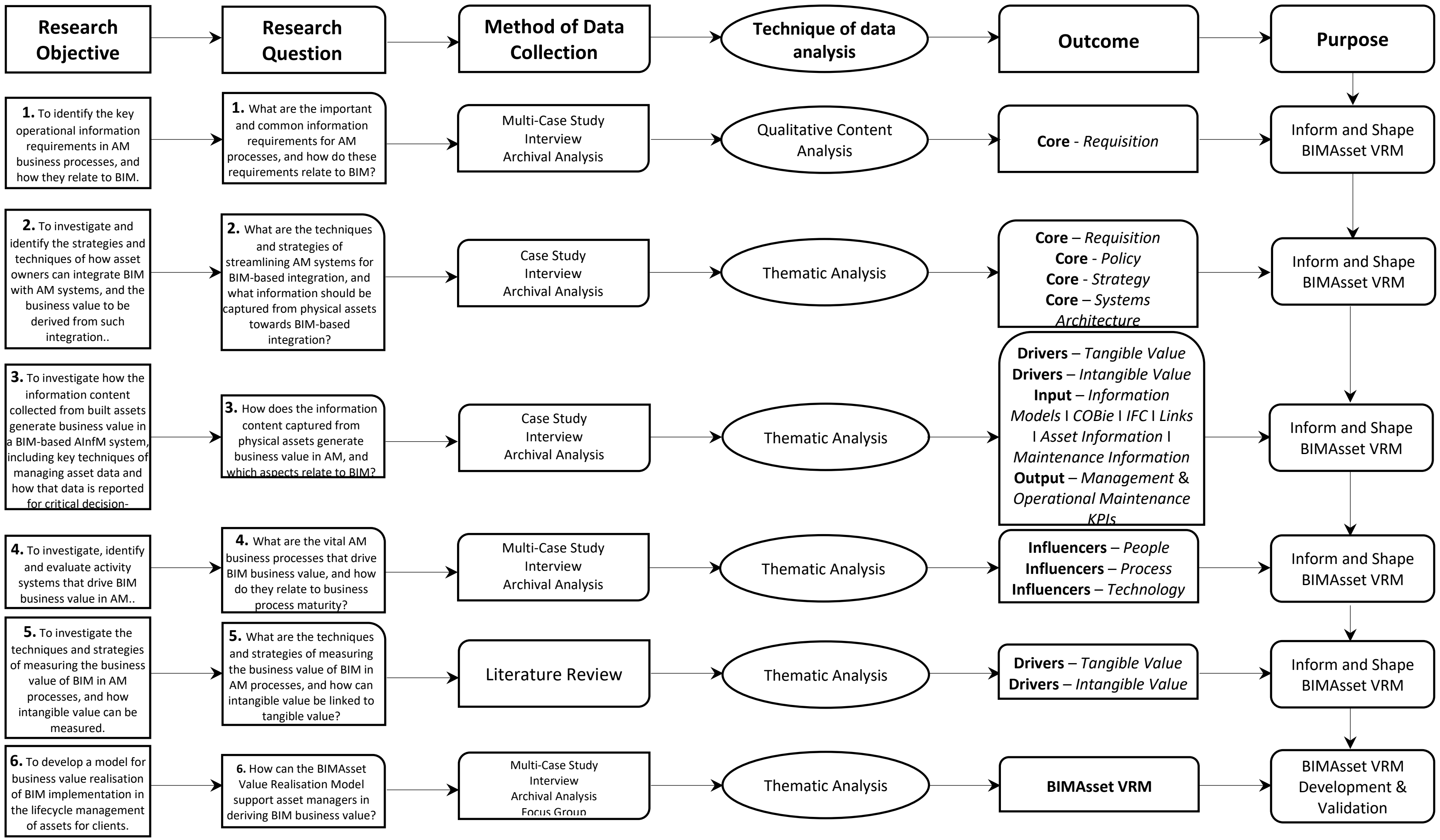


Figure 3.4: Research Flow and Tasks

3.7.1 OBSERVED PROBLEM

This aspect of the CIFE '*horseshoe*' refers to the identification of the research problem that is described and justified by the study, which may lead to a defensible contribution to knowledge (Fischer, 2006). The researcher observed the research problem, which is the lack of adoption of BIM in AM and weakness in BIM value realisation methods in AM. The observed problem has been documented in Sections 1.1 and 1.3. Furthermore, Fischer (2006) highlights the need for a research project to start with a precise problem definition with clear criteria for success that are not too broad or vague in order to yield a productive research process with strong research results. In view of this, the research scope is defined in Section 1.2.

3.7.2 INTUITION

Intuition is required by the researcher on how to address the identified problem (Fischer, 2006). Here, the researcher engaged industry experts who were early adopters of BIM in AM to validate the identified research problems from the literature. These industry engagements were carried out as single and group interviews. The industry engagement profile is shown in Table 3.7.

Table 3.7: Showing the research industry engagement profile

S/NO	INDUSTRY ACTOR	COUNTRY	INDUSTRY SECTOR	JOB DESCRIPTION	DATE
1	Client/Owner	UK	Education	Architectural Assistant, Facilities, Residential and Commercial Services	16.03.17
2	Client/Owner	UK	Education	Architectural Assistant, Facilities, Residential and Commercial Services	25.07.17
3	A. Client/Owner/Contractor B. Client/Owner/Contractor C. Client/Owner/Contractor	UK	Mixed use	A. Head of Digital Engineering B. BIM Knowledge Hub Community Manager C. BIM Specialist	03.05.17
4	Consultant	UK	Retail	Associate Director	26.05.17
5	Consultant	UK	Retail	Chairman	24.05.17
6	A. Client/Owner B. Client/Owner	UK	Government-Mixed use	A. Programme Manager B. Estates Information Manager (Digital Engineering)	07.06.17
7	Contractor	UK	Mixed Use	Pre-construction Feasibility Project Manager	10.07.17
8	Client/Owner	UK	Education	Building Surveyor, Facilities, Residential and Commercial Services	22.08.17
9	Consultant	UK	BIM Consultancy Director	Consultant	27.09.17
10	Consultant	Finland	Building services MEP	Technology Director	10.10.17
11	Client/Owner	UK	AM	Director Digital Services	29.08.17
12	Client/Owner	UK	FM	Projects and Innovation Manager	29.01.18
13	Client/Owner	Finland	Building Services FM	Director Facility Maintenance Digitalization	20.04.18

After the industry engagements, the researcher drew mind maps using the NVivo™ software about how the research problem could be addressed (Bazeley and Jackson, 2013). The researcher categorised the research into themes or studies and to develop a research map on how they would all contribute to the development of a model which would assist clients in deriving BIM business value in AM.

3.7.3 THEORETICAL POINT OF DEPARTURE

A well-defined research problem enables solid theoretical starting point for the research (Fischer, 2006). The theoretical point of departure for this study is developed systematically, firstly by identifying the generality of the problem through a literature review on the lack of adoption of BIM in AM. Secondly, these findings were validated through industry engagements. Thirdly, existing theories were identified that were useful in articulating the problem and identifying aspects of theoretical limitations that will guide the literature review. The theoretical point of departure is covered in Section 1.5 of this thesis.

3.7.4 RESEARCH QUESTIONS

The research aims, objectives and questions for the study are conscientiously developed as a result of the theoretical point of departure. The theoretical point of departure identified five factors as reasons for the lack of BIM business value realisation by asset owners. As such, the study developed the research questions in Section 1.7.

3.7.5 RESEARCH TASKS, METHODS AND PLAN

The study's research methods are carefully selected to answer the research questions and to attain the research aim and objectives. The research methods adopted for the study are expressed in this section of this study. Furthermore, more detailed aspects of the methodology in relation to individual research themes or studies have been described in Sections 4.3, 5.3, 6.3, 7.3 and 8.3 of the thesis. Also, further examination of the selected research methods is conducted against study limitations identified in Section 11.6.

Every research task has to be properly defined, scoped, designed towards a research objective, process-managed and results reported (Fischer, 2006). The research tasks carried out in this study involves seven standard processes followed by the researcher against every research problem or question. They are: (1) Review Literature to identify gaps; (2) Engage industry experts to validate gaps; (3) Develop research questions and proposals based on 1 and 2; (4) Identify respondents and research methods; (5) Collect and analyse data using 4; (6) Document and report findings based on 5; and (7) Contribute to BIMAsset VRM development. These are shown in Figure 3.6:

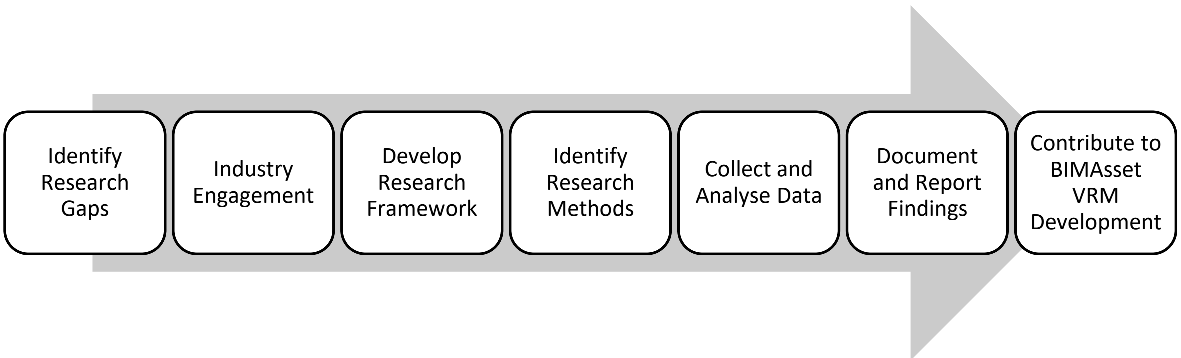


Figure 3.5: Research tasks

3.7.6 RESULTS AND VALIDATION

The results obtained at the end of each task were checked against the research methods and questions for both internal and external validity. These results included evidence which are presented in Section 4.4, 5.4, 6.4, 7.4, 7.5, and 8.4. A Focus group or expert panel is conducted for validity as stated in Section 3.5.3, and the results are discussed further in Chapter 9 of this study. During validation, the research outcomes are shown to the expert panel to ask whether the approach covers important concepts of the domain adequately and whether results make sense (Fischer, 2006). Furthermore, the research results have been checked for consistency with the problem definition, the ability to answer the research questions, and completeness to attain the aims and objectives of the study. These have been addressed in Section 11.3 of the thesis.

3.7.7 CLAIMED CONTRIBUTIONS

The research makes academic and practice-based contributions. The research contributions and validated results extend the existing knowledge base and contribute to new concepts and approaches in BIM business value realisation (Fischer, 2006). The validated outcome of the research provides a model for clients to realise the business value of BIM implementation during asset operations in an AM system. The theoretical contribution of this study is the contribution to literature and development in the understanding of: the information to be requested for BIM-based processes; how it should be captured and managed including the valuable information attributes; how outcomes can be observed; and how value can be tracked in an AM system during asset operations. This has improved the understanding of BIM-business value measurement techniques and approaches during asset operations. The study contributes to knowledge by helping to ameliorate the industry weakness in measuring BIM business value and in tracking intangible BIM benefits within owner-operator organisations. The practical contribution of this study is the provision of a framework that will guide asset owners in tracking tangible and intangible value for measurement in an AM system. The contributions to knowledge of this study have been presented in more detail in Section 11.4. Also, recommendations for future work are presented in Section 11.5.

3.7.8 PREDICTED IMPACT

Although this is the last task, research projects often start here with the vision for the desired impact (Fischer, 2006). This task is conducted to review the research outcomes with the same metrics that were used to define the problem (Fischer, 2006). Recommendations are made to asset managers for the implementation of the BIMAsset VRM in asset operations. Sections 8.5 and 11.4.2 of this thesis deal with the practical significance to this study. The practical significance of the BIMAsset VRM lies in its proficiency to enable asset owners to derive BIM business value in an AM system during the operations and use phase.

3.8 ETHICAL CONSIDERATIONS

Ethics refer to the rules of conduct, the standard of behaviour and conformity to a set of principles (Robson and McCartan, 2016). Saunders, Lewis and Thornhill (2016) suggest that ethical considerations would emerge as researchers plan their research, seek access to collect data, analyse and report data. Research ethics are overarching concerns when adopting a research strategy and it is necessary to gain approval from any relevant authorising body or ethics committee (Denscombe, 2010; Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Fellows and Liu (2015) suggest six general principles of research ethics, and they are; integrity and quality, informed consent, confidentiality, voluntary participation, avoid harm to participants, independence, and declaration of conflicts of interest. Similarly, Saunders, Lewis and Thornhill (2016) present ten ethical principles, they are; integrity and objectivity, respect for others, avoidance of harm, participant privacy, voluntary participation, informed consent, ensuring confidentiality, responsibility in data analysis, data management, and ensuring the safety of the researcher. Furthermore, Fellows and Liu (2015) recommend three general principles of ethics during data collection use and disposal, and they are; informed consent, assessment of risk and benefits, and selection of subjects. These guidelines were adhered to during data collection. To continue, Fellows and Liu (2015) propose eight data protection principles and highlight that data must be; obtained lawfully, compatible with research purpose, adequate and relevant for the research purpose, kept up to date, kept safe from unauthorised access, kept for a period no longer than necessary, used in accordance with the rights of the participants, and transferred only to domains that have sufficient protection of personal data.

Gaining ethical approval from the University of Liverpool Ethics Committee is paramount for the conduct of this research. The ethical approval application is guided by the University guidelines, which were followed through by the researcher since the research will involve human participants through face to face, telephone, video or through focus group interviews (Denscombe, 2010; Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2016). Prior to the conduct of interviews, the participants are informed on the study in great detail, their consent is sought, and the data collection procedure explained to them. Furthermore, participants are informed of their right to withdraw from the study at any point in time they wished. This is to ensure that the rights of participants are respected, avoid harm to participants, and conduct the research with honesty and integrity (Denscombe, 2010). However, no participant withdrew their consent nor participation during the period of study. All confidential data collected by the researcher is stored on the researcher's secure and daily backed-up storage drive. The researcher made sure that all of the data collection and analysis activities conformed to the ethical principles of studies with human participants (Denscombe, 2010). The participant information sheet, participant consent forms and ethical approval letter are attached in Appendixes A and C.

3.9 CHAPTER SUMMARY

This chapter presents the different methodologies available and choices utilised for this study, including sufficient justification. The study adopts a relativist and interpretivist ontological and epistemological stance. Abductive reasoning is the selected research approach. The research strategies adopted are case study, archival analysis and grounded theory. Methodical choices are qualitative, exploratory and descriptive. The study adopts semi-structured interviews and focus group research techniques. The time horizon for the study is cross-sectional since doctoral studies are time-bound. The study adopts the CIFE '*horseshoe*' research design. Finally, the study discussed and explained the ethical considerations in the context of this study. Table 3.8 shows the summary of the research methodology adopted for the conduct of this study.

Table 3.8: Summary of research methods adopted and rationale

S/NO	METHODOLOGICAL PARADIGMS	RESEARCHER'S CHOICE	RATIONALE
1	Research Philosophy	Ontology: Relativism	Due to the context of the research which views the world as having no objective reality but merely a number of subjective truths.
		Epistemology: Constructivism/ Interpretivism	Due to the research context of which views that there exist multiple realities that are constructed by the researcher based on meanings and interactions within the research setting.
2	Research Approach	Abductive	Due to the nature of the research objective which aims to study phenomena and to develop a theory or framework that explains or addresses them.
3	Research Strategy	Case Study	This is utilised in order to study individual, organisational and social-related phenomena.
		Archival Analysis	This is utilised to make use of administrative documents and records as one of the principal sources of data.
		Grounded Theory	This is adopted in order to generate theories to explain and address an aspect of the phenomenon under study.
		Exploratory	This is utilised to gain insights in order to develop an understanding of the phenomenon.
		Descriptive	This is utilised in gaining accurate profiles of the phenomenon.

S/NO	METHODOLOGICAL PARADIGMS	RESEARCHER'S CHOICE	RATIONALE
4	Research Methodological Choice	Qualitative	This is utilised to gain insights within the research context by eliciting information on people's experience, feelings and priorities.
5	Research Techniques	Semi-Structured Interviews	This is utilised in collecting data by asking questions and recording responses of participants and in probing further by asking supplementary questions in order to obtain more details and to pursue new interesting aspects within the research context.
		Document Analysis	This is utilised to source for records, artefacts and archives for analysis within the research context.
6	Data Collection	Primary Data: Interviews and Documented Data.	Due to the nature of the research which involves the documentation of the perception of participants and collection of documented data from the field.
		Secondary Data: Literature Review	Due to the nature of the research which involves reviewing literature in order to explore phenomena within the research context.
7	Sampling	Purposeful Sampling: Operational Construct Sampling	This is utilised to collect data from a sample that is readily available within the theoretical constructs of the research.
		Purposeful Sampling: Snowballing	This is utilised in exploring network in order to obtain data from samples that are difficult to access.
8	Data Analysis	Qualitative: Thematic Analysis	This is utilised for encoding qualitative information in the form of codes and themes to categorise potential observations at the minimum or to interpret characteristics of a phenomenon at the maximum.
		Qualitative: Content Analysis	This is utilised to analyse visual, verbal or written organisational documents within the research context.
		Quantitative: Descriptive Statistics	This is utilised because some aspects of the qualitative research data required systematic and standardised comparisons using quantitative descriptive statistics in order to graphically present the study data
9	Research Time Horizon	Cross-Sectional	Due to the nature of the research programme, which is time bound.
10	Research Design	CIFE *horseshoe*	This design allows the researcher to formalise new knowledge in the AEC industry in circumstances where it is difficult to replicate situations found in practice.
	Validation	Focus Group (expert panel)	This is utilised in order to validate whether the research area has been adequately covered by the outcomes of the study through expert opinion.

S/NO	METHODOLOGICAL PARADIGMS	RESEARCHER'S CHOICE	RATIONALE
		Participant Validity	This is utilised in order to validate whether the collected data represents the views of the participants.
11	Ethical Considerations	Consent	This is utilised to ensure voluntary participation and to obtain data lawfully during the course of the research.
		Privacy	This is utilised to ensure participant privacy and to avoid harm to participants as a result of their participation.
		Confidentiality	This is utilised in order to keep collected data safe from unauthorised access.

CHAPTER 4

BUSINESS VALUE OF OPERATIONAL INFORMATION REQUIREMENTS

UNIVERSITY OF LIVERPOOL

4.0 BUSINESS VALUE OF OPERATIONAL INFORMATION REQUIREMENTS

4.1 CHAPTER INTRODUCTION

This chapter presents the study relating to Research Objective 1: To identify the key operational information requirements in AM business processes and how they relate to BIM. This chapter seeks to address one of the research gaps identified in Chapter 2. That is, the lack of knowledge and understanding amongst asset owners in the development of operational information requirements for BIM-based processes. Considering the research problem, this is a technical (BIM-AM systems) and social (organisational or management) challenge that is two-fold. First, asset owners are not able to define their requirements. Second, the required data cannot be delivered by the technological systems during asset operations since the requirements have not been articulated. This is also due to the lack of awareness on the use and capability of the technological systems. Therefore they do not get the right data they need to effectively manage their built assets. The underlying assumptions here are that asset owners should have the capability to identify their operational information requirements amongst many challenges of implementing BIM during asset operations. The study implies the need for the asset owner to probe and understand information requirements for BIM utilisation in the operations and use phase. This underlying organisational approach or understanding could have a profound influence in BIM adoption. Three companies are involved in this multi-case study approach to achieve the research objective in identifying the key operational information requirements in AM business processes. Three operational information requirement templates are evaluated in order to identify those information requirements that are useful to asset managers for maintaining their built assets. The rationale here is that for there to be any value in BIM-based AM processes, the asset owner needs to understand what the deliverables are; and without understanding and defining the requirements properly, the resulting output will be unreliable and of no economic value. This chapter seeks to provide guidance to asset owners for them to be able to articulate key requirements so as to realise business value from BIM-based processes during asset operations. The importance of this chapter with respect to the development of the BIMAsset VRM is that it provides a better understanding of the justification that was made by the researcher for each of the identified elements and sub-elements. These findings are discussed and theoretically validated in Chapter 9.

4.2 RESEARCH JUSTIFICATION

Building information modelling (BIM) can offer significant support to asset owners in the lifecycle management of their information assets. This can be achieved through enhanced data management, data usability, real-time data access, visualisation, and efficiency in maintenance management (Becerik-Gerber *et al.*, 2012; Cavka, Staub-French and Poirier, 2017). Increasingly, asset owners are developing guidelines and deliverables for BIM-based processes to address the challenges associated with poor information fidelity (Kensek, 2015; Cavka, Staub-French and Poirier, 2018). This is due to the fact that asset managers rarely get the data that they need because such information is usually embedded with significant amounts of unusable parameters (Brous, Herder and Janssen, 2016). Moreover, operational personnel commonly struggle to articulate their BIM-based information requirements; and when they are asked to specify the requisite data that are critical for asset operations, they ask for everything (Hoyer, Maclnnis and Pieters, 2013). As a consequence, operational personnel are overloaded with information and are unable to filter the essential data needed to perform AM tasks and derive BIM business value in asset operations. The inability of asset managers in the AEC industry to articulate their operational information requirements from the design and construction phases is one of the biggest barriers to BIM implementation in asset operations (Becerik-Gerber *et al.*, 2012). Hence, there is a need to research the ways in which to identify operational information requirements for BIM-based processes.

Understanding the information needs of asset managers can be difficult, especially when trying to capture the feelings and perceptions of users for an intangible resource within owner-operator organisations (Irani, 2010). This is because people rarely focus on their needs and values, and as a result, experience difficulties in their articulation (Hoyer, Maclnnis and Pieters, 2013). Furthermore, Cavka, Staub-French and Poirier (2017) highlight the following as reasons for the lack of understanding in developing information requirements by AM personnel: (a) lack of sufficient set of information to support asset lifecycle information; (b) lack of experience of BIM-based processes to be able to determine the level of information needed; and (c) lack of awareness on how to request information to support BIM-based processes in asset operations. Furthermore, there are no comprehensive details to support the execution of Employer Information Requirements (EIR) activities, and this is due to an insufficient understanding of the requirement specifications, processes and competencies amongst stakeholders in the operations and use phase for real value to be realised (Ashworth, Tucker and Druhmann, 2017b; Jupp and Awad, 2017). It is therefore essential for organisations to define operational information requirements, which can be used to request and identify the right information based on well-defined criteria that are aligned with business needs and business value realisation management (Levitan and Redman, 1998; Love *et al.*, 2014; Brous, Herder and Janssen, 2016). Asset managers need to understand the management and operational implications of BIM implementation and how their data needs will be delivered. However, it is the role of the asset owner to develop an information requirement specification or template for utilising BIM in AM. This can be done by the top management translating the business value to organisational goals and by allocating the responsibility of specifying the information needed to achieve the organisational goals to a department or person. Also, in order to realise the value of information, data users must ultimately understand its nature and determine its suitability for intended use in the organisational business processes (Dawes, 2010). As such, there is a need to develop industry standards that define processes, data protocols, and the relationship between data and business needs in order to derive value from the BIM-based processes in AM (Love *et al.*, 2014; Jupp and Awad, 2017).

Another challenge that asset managers encounter is insufficient, incomplete or incorrect data, given that contractors and suppliers only produce data which they themselves require (Brous *et al.*, 2014). Similarly, Korpela *et al.* (2015) suggest that models used for design are not suitable for maintenance and that there is a need for careful specification of purpose and of the level of detail including model contents. Furthermore, the optimal amount of information to be included in the model for BIM-based processes is yet to be determined (Mayo and Issa, 2014). As a result, data delivered for use in asset operations is lacking from the perspective of AM. In most instances, handed-over data does not conform to the physical assets installed and sometimes updated asset information in information models is not passed comprehensively to the user organisation (Lin, Gao and Koronios, 2008). Hence, asset and facility managers end up with redundant and out-of-date documentation, thereby restricting the value that BIM can bring to the organisation.

The introduction of BIM and especially Construction Operations Building Information Exchange (COBie), aimed to provide asset and facility managers with the necessary information to manage and operate a facility. However, the AEC industry is confronted with the challenges of identifying essential datasets for asset operations, which is due to the multitudinous data dimensions provided by COBie. The availability of more data does not automatically translate to better information or more informed decisions. Indeed, it is estimated that more than 70% of the data generated in owner-operator organisations are never used (Lin, Gao and Koronios, 2008). Moreover, asset managers claim to be drowning in data but yet starving for information (Lin *et al.*, 2007). Hence, there is a need to study and identify what asset managers actually need to do their work in order to derive value from BIM-based AM data.

Operational information requirements in the context of this study refer to vital organisational requirements relating to AM business needs and processes, such that when utilised, it results in an immediate impact on BIM business value realisation for the asset owner. These operational requirements constitute some aspects of requirement components contained in the OIR and AIR. This study focuses on three issues: (a) lack of clear understanding of the information needs in AM business processes; (b) an analysis of the most frequently defined operational information requirements; and (c) how these requirements are defined and structured in the operations and use phase. An essential aspect of those requirements are the business needs, including the use of COBie and linked data which is aimed at effective information delivery from the design and construction stages to asset operations. Therefore, this study investigates the operational information requirements of three asset owners through a comparative study in order to identify the strategies, tools and techniques for requirement development and the most commonly defined information requirement by asset owners.

4.3 CHAPTER 4 – DETAILED METHODOLOGICAL APPROACH

This study aims to identify key operational information requirements in the context of business needs and how these requirements relate to BIM through a comparative study. The research seeks to investigate how operational information requirements link to business needs and BIM business value. It also seeks to identify effective strategic approaches for capturing operational building information requirements for BIM-based processes. This study aims to address the following research questions:

- What are the important organisational information requirements for AM processes, and how do these requirements relate to BIM?
- What are the common operational building information requirements for asset owners?
- What are the strategic approaches of developing operational information requirement templates by asset owners?

4.3.1 RESEARCH METHODS

This study adopts the case study and archival analysis research strategies to evaluate the operational information requirements of three asset owners. This approach is used to document the operational building information requirements. That is to compare and identify the most common operation information requirements defined amongst asset owners. Archival analysis is utilised to analyse the operational information requirements in each case study.

The literature review helped to explore established strategies for documenting building information requirements (Sections 2.12 and 4.2). It seeks to identify frameworks and methodologies developed by other studies in relation to the information requirement strategies, methods, tools and techniques. The second phase involves the multi-case comparative research, where operational information requirements are evaluated through a comparative analysis. This phase is divided into two stages, namely the interviews and document analysis. The three cases are compared based on the criteria that: (i) they are experienced users of BIM; (ii) they utilise BIM in AM; (iii) they have developed operational information requirement templates for utilising BIM in AM. As such, the basis for comparison here is the operational information requirement template developed by the three case studies. These templates are analysed, and the similarities and differences reported. The units of analysis are the strategies adopted for the development of the requirement templates, its structure and operational style. Another unit of comparison were the interview questions. The three case studies were asked the same questions in relation to the development of the operational information requirements. Therefore, this justification established that:

- The same interview questions were asked (for the three cases). Hence, there is a basis for comparison, in terms of the primary data from the interviews.
- All three cases have developed information requirements. Hence, there is a basis for comparison, in terms of the primary archival data.

Although the selected case studies are from different sectors, this factor does not affect the process of developing operational information requirements.

4.3.2 RESEARCH PROCESS: DEDUCTIVE REASONING SRQ-1

This section presents the methodological process of this part of the study. Here, deductive reasoning is adopted for SRQ-1 in understanding and identifying key information requirements for asset owners to be able to realise BIM business value in the long term. This aspect of abductive inference of the PRQ concerns the investigation of three owner information requirements that are sourced from the AEC industry. This is shown in Figure 4.1:

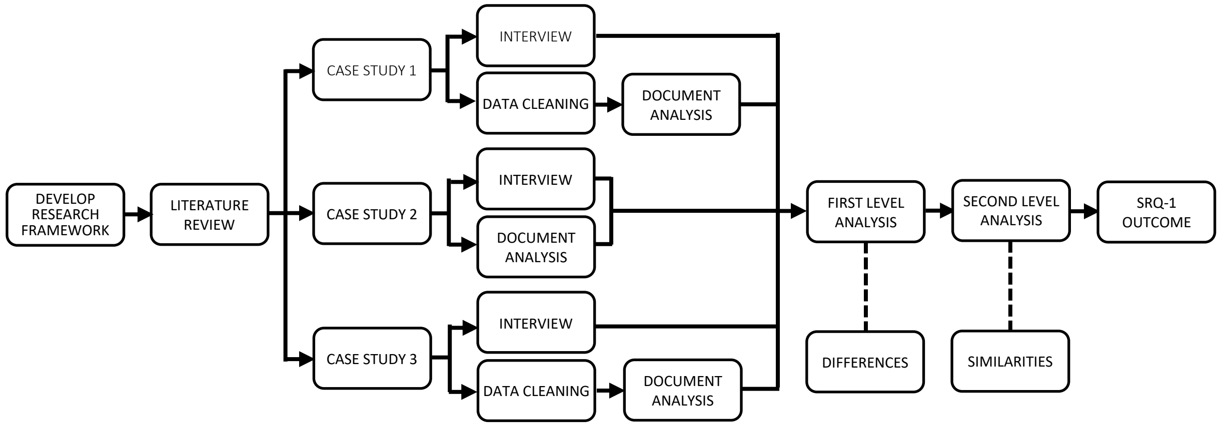


Figure 4.1: Deductive reasoning SRQ-1

4.3.3 CASE STUDY SELECTION

This study utilises purposeful and snowballing sampling strategies to identify the cases and respondents. Operational construct sampling as a type of purposeful sampling is used to select case studies that are representative of the asset owners that have developed their operational information requirements. Due to scarcity of templates for the development of information requirements for BIM-based processes in the AEC industry, snowballing is used to explore networks in order to identify participants (Saunders, Lewis and Thornhill, 2016). The samples of asset owners selected for this study are from different sectors in order to compare perspectives in terms of the development of operational information requirements in AM. The cases and participants have the following characteristics:

- Case Study 1: Company A – This is a Finnish mechanical, electrical and plumbing (MEP) consultant that manages the operational data of over 1,000 clients globally through BIM. This company has developed a standard operational information requirement template for its clients.
- Case Study 2: Company B – This is a health sector owner-operator that owns and manages about 125 buildings, of which 4 buildings and 1 hospital are managed through BIM-based processes. This asset owner has developed its standard operational information requirement template for internal data needs and operational maintenance activities.

- Case Study 3: Company C – This is an education sector client that owns and manages about 378 buildings through BIM-based processes. This asset owner has developed an operational information requirement template for internal business and data needs in asset operations.
- All participants have advanced knowledge of BIM in asset operations.
- All participants are senior personnel responsible for the development of operational information requirements template.

The above criteria are designed to ensure that the selected cases and participants cover a reasonable scope in relation to different typologies of asset owners. The participants experience and knowledge of BIM were assessed during the preliminary interviews and discussions prior to the interviews.

4.3.4 DATA COLLECTION AND ANALYSIS

This study adopts a qualitative approach to data collection and mixed methods analysis. This is because some aspects of the qualitative research data required systematic and standardised comparisons using quantitative descriptive statistics in order to understand the study data and graphically present the results. This allowed for the gathering of information from the selected sample in order to identify the most commonly defined operational information requirements by asset owners. Interviews and document analysis are utilised to collect and analyse the data. The benefit of using interviews is that it enables the probing of issues regarding the operational and business-level information needs, thus, making it an effective investigative tool. During the course of the study, three interviews are conducted, with one for each case. The interviews helped to obtain qualitative accounts of the organisational approaches to developing operational information requirements. The study utilises the NVivo™ software to transcribe, code and analyse the interview data (Saunders, Lewis and Thornhill, 2016). The coding technique enabled the easy analysis and cataloguing of the primary interview data (Boyatzis, 1998).

The study investigates internal documentation such as information requirement templates, ICT specification standards, BIM implementation plans (BIM IP) and BIM Execution Plans (BEP). Here, mixed methods are used to analyse these documents through a content analysis technique. This technique enabled the qualitative multi-case comparative analysis. Furthermore, a qualitative word frequency analysis is adopted in order to make inferences on the most commonly defined information requirements (Stemler, 2001). Additionally, quantitative descriptive statistics such as bar charts and stacked bar charts, are used to comparatively analyse the distribution of information requirements across the requirement definition categories within the three selected case studies. These charts are generated using Microsoft Excel™ software (Walkenbach, 2015).

Furthermore, the operational information requirements of the three case studies are analysed during a document analysis. First, data cleaning is carried out in order to detect and remove inconsistencies in order to improve the quality of the data (Saunders, Lewis and Thornhill, 2016). This stage is necessary because operational information requirements, which included other documentation, have been translated from Finnish to English (Company A) and from Danish to English (Company C). Second, the operational information requirements are read to understand the context of their application. The properties and property sets are then sorted into tables under the headings of business sector, general classification, standard description, general description, location description, installation description, product description, technical description, physical description and model reference. The sorting process is done iteratively until the information requirements are consistently grouped. Third, the first-level analysis is carried out to determine the differences across cases. Fourth, the second-level analysis is conducted to identify similarities in the operational information requirements. Finally, due to the selection of the case studies, it is acknowledged that the results could be biased towards certain sectors of the AEC industry.

4.4 RESULTS: COMPARATIVE ANALYSIS

The results presented in this section and sub-sections are from the findings of the semi-structured interviews and archival analysis.

4.4.1 FIRST LEVEL ANALYSIS: DIFFERENCES

This aspect of the analysis involves the analysis of differences within the general structure of the operational information requirement templates. These are analysed under classifications such as business sector, strategy, BIM data perspective, general structure and object category. Table 4.1 shows the schematic analysis of the three cases.

Table 4.1: Comparative analysis of operational information requirements schematic structure

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C
1	Sector	MEP	Health	Education
2	Strategy	Co-development (COBIM Requirements/ buildingSMART)	Environment of Care	Data Ambassadors
3	BIM Data Perspective	IFC	Native Models (REVIT)	Native Models (REVIT)
4	General Structure	1. Attribute-sets definition. 2. Individual elements covered in Object Category below. 3. Individual systems or objects according to business needs.	1. Attribute-sets definition. 2. Individual elements covered in Object Category below. 3. Individual systems or objects according to business needs.	1. Individual elements covered in Object Category below. 2. Individual systems or objects according to business needs.
5	Object Category	1. Building Automation. 2. Pipes. 3. Electrical Installation. 4. Ventilation Installation. 5. Individual systems or objects according to business needs.	1. Building fabric shell. 2. Interior. 3. Conveyor and lifts 4. Plumbing. 5. Heating, ventilation, and air conditioning (HVAC). 6. Fire protection. 7. Electrical. 8. Equipment. 9. Individual systems or objects according to business needs.	1. General building parts (building fabric). 2. BMS Automation. 3. Electrical Installation. 4. Landscape. 5. Land. 6. Terrain. 7. Ventilation Installation. 8. Plumbing Installation. 9. Individual systems or objects according to business needs.

4.4.1.1 SECTOR

Business sector refers to classifications made between organisations in relation to the aspect of the economy and the operational focus of the information requirement template. From the above analysis, the three cases represent different business perspectives, namely MEP, Health and

Education. Company A is a MEP consultant that specialises in building services engineering. These requirements range from mechanical (heating, cooling, escalators, etc.), electric (power supply, lighting, control systems, etc.) and plumbing (pipes, drainage, fuel gas, etc.). Company B is a healthcare client who owns and operates healthcare buildings that contain facilities such as operating theatres, wards, outpatients, acute care inpatients, pharmaceutical compounding, laboratories, stem cell and accident and emergency units. These special requirements range from noise and vibration control in sensitive areas such as hospital operating theatres. Company C, as an education sector client, has a wide range of different academic buildings consisting of offices, classrooms, lecture theatres, and laboratories. These all have different requirements in terms of: spatial planning, the flexible use of space, the control of vibrations and acoustics.

The above analysis indicates that the business sector of the asset owner has a relationship with the nature and type of information needs for BIM-based processes. As a result, the data requirements for Health and Education will be different.

4.4.1.2 STRATEGY AND BIM DATA PERSPECTIVE

Strategy refers to the process of planning and allocating organisational resources to identify key data requirement leading to the development of the operational information requirement templates for BIM-based processes in order to achieve organisational objectives. These development strategies differ across all three cases, including their BIM data perspectives. Data perspective relates to the organisational focus in the standardisation of selected aspects of the operational information requirements and how represented within BIM-based processes in the organisation. Company A uses ‘*Co-development*’, Company B uses ‘*Environment of Care*’, and Company C uses ‘*Data Ambassadors*’. Furthermore, the BIM data perspectives also differ as Company A uses IFC with COBie, Company B uses native models with COBie and Company C uses native models with linked data.

The data requirement development strategy of Company A is guided by the Finnish Common BIM (COBIM) requirements, and uses the buildingSMART Finland property set tables. This is because their BIM data perspective is IFC. The operational information requirements were prepared through '*Co-development*' with asset owners and other stakeholders in the AEC industry in Finland. However, Company A highlighted that the operational information requirements (attached in Appendix H) are continuously developed; thus the reviewed may not represent the final version because the business is still trying to understand the phenomena related to BIM requirements in asset operations.

Secondly, Company B adopts a unique strategy of specifying a higher level of detail and development on an identified 5% asset requirement scope within their developed '*Environment of Care*' requirement template. Although, Company B uses great portions of the other remaining 95% asset requirements, they do not highly specify them. Instead, they allow the delivery of the requirements in accordance with the BEP and information delivery standards so as not to increase the cost of the whole process. These include mechanical, electrical, plumbing, water distribution, trade models, architectural models, CMMS, predictive, preventive and regulatory requirements that promote a safe, functional, and supportive environment within the organisation. The 5% essentials are uniquely and prescriptively defined in the contractual documents and are shown in Appendix I. Company B's data perspective is using native building information models through Revit.

Thirdly, Company C's strategy for data requirement development is through the establishment of a BIM office that serves as '*Data Ambassadors*' when structuring and communicating data within the organisation and across business units. This is because Company C's operational information requirements are generic and need to be specified further by the BIM office for every project. The operational information requirements were developed over a long period of time by interviewing departmental operational staff about each system and each component. Furthermore, whenever there is a request for data from the operational department, the BIM office acts as information brokers to deliver these kinds of data for asset operations. The requirements attached in Appendix J are specified in contractual documents. However, the BIM office is only responsible for developing the operational information requirements template and for translating what the operational department wants in the BIM context; therefore the data content continues to be owned by the operational department. So, the BIM office is only translating what the operation department requires. In other words, the BIM office is not responsible for what is in the template, but rather what parameters are available for which component. As such, Company C's data perspective is using native building information models through Revit and linked data.

In consideration of this analysis, the organisational strategy underpinning BIM implementation guides the operational information requirement template. Aspects such as change management strategies, BIM-AM systems, systems architecture, network requirements and individual user requirements represent factors that influence the nature and content of operational information requirements. Therefore, the typical nature of any asset owner is markedly different, and these organisational protocols make it difficult to maintain the same operational information requirements; this is particularly the case amongst organisations within the same sector. Furthermore, these aspects highlight that there are internal and external factors that influence business needs and operational information requirements for BIM-based AM processes that drive business value. Business needs are referred to as requirements (operational and strategic) that drive organisational processes in order to achieve business objectives. In this context, business needs refer to AM requirements that facilitate the utilisation of reliable data provided by BIM-based processes in order for an asset owner to achieve business objectives. Internal factors concern endogenous characteristics such as organisational structure, strategy, technology, protocols and human resources. External factors refer to exogenous aspects such as statutory requirements, environmental requirements and industry standards. Therefore, it is not possible to develop a one fit for all operational information requirement template that will meet the needs of asset owners from all sectors.

4.4.1.3 SCHEMATIC STRUCTURE

Schematic structure relates to the outline highlighting the logical connections between components of the operational information requirements template. The schematic structures are different and have diverse classifications for requirements across all cases. Although, Company A and Company B have a defined attribute definition sheet, Company C does not. The attribute definition sheet contains standards for data reporting, including data types (text, number, link, list, date, etc.), units, and detailed information on object property. Company A has a group of headings with a matrix structure to identify the information requirements against the property sets, property, objects and software specifications. Company B and Company C have a field entry system against the property sets and objects. Although, Company A specifies text, numeric and other types of data requirement, there are no fields for entering such information on the requirement sheet as it is delivered through the IFC. Company B and Company C have a field entry system with numeric, text and value fields that can be extracted through COBie or linked data.

Nevertheless, considering the above, the schematic structure is an aspect that can be standardised by the AEC industry. Therefore, it is possible to develop a standard meta-requirement template to provide a general structure through which asset owners can request information.

4.4.1.4 OBJECT CATEGORY

Object category refers to the arrangement of concepts and elements in relation to the operational assets of the information requirements template. The scope of object categories and individual objects of interest across all three cases are different. Here, Company A as a MEP consultant have the smallest scope that only covers the mechanical, electrical and plumbing aspects. These are shown in Table 4.1 and Appendix H. On the other hand, Company B focuses on a wide range of object categories that are critical to their business needs as a health sector client. These are shown in Table 4.1 and Appendix I. Company C as an educational sector client has the widest range of requirements due to the differing natures of the building types within their asset operations. These are shown in Table 4.1 and Appendix J.

In view of the fact that the object categories of all three cases represent different systems or objects that are critical to the business needs of each client, it may not be possible to develop a rigid list of requirements that are applicable to all asset owners. Guidance templates and notes can be developed to highlight some categories that will help asset owners define their data requirements. Furthermore, developing a widely scoped requirements list that contains every piece of information will have its drawbacks as there will be too many data fields to input. As such, personnel in the construction phase would find it too arduous to populate, and the delivery of this type of dataset would be excessive for asset operations personnel, who will find it challenging to filter the necessary information sets in order to execute AM tasks.

4.4.2 SECOND LEVEL ANALYSIS: SIMILARITIES

This analysis is based on the operational information requirements template of the three asset owners. Here, the requirements defined in the three cases are probed to identify similarities and the most common information requirements. This aspect of analysis consists of the property and attribute sets of the operational information requirements, such as (but not limited to) Object ID, Manufacturer, Model Type and LOD (Level of Detail or Development). This study utilises the following classifications to group information requirements; business sector, general classification, standard description, general description, location description, installation description, product description, technical description, physical description and model reference. Here, all the defined requirements are added to the property set classification headings. Table 4.2 includes only information requirements that have been defined in at least two cases and shows the information requirements, including how many times they have been defined. The Themes Column consists of the properties and property sets, whilst the Company A, Company B and Company C Column indicate the defined requirements and specify the case. Moreover, the Number Column specifies the number of cases that have defined that requirement. The full extract of the operational information requirement template list is presented in Appendix G.

Table 4.2: Summary of requirements across all cases

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C	NUMBER
1	Sector	MEP	Health	Education	
2	General Classification				
a.	Attribute or Property Information	●	●		2
b.	Classification System (IFC, Uniclass, OmniClass, SFB, CCS, or ISO)	● (IFC and OmniClass)	● (OmniClass)	● (SfB and CCS)	3
c.	COBie Information	●	●		2
d.	Description		●	●	2
e.	Object, Product or System	●	●	●	3
f.	OmniClass Name	●	●		2
3	Standard Description				
a.	Building, Object, Product or System Name	●	●	●	3
b.	Level or Storey	●	●		2
c.	Link or Reference to Model	●	●	●	3
d.	System Code or Number	●		●	2
4	General Description				
a.	BIM Authoring Software Parameter Name	●	●		2
b.	BIM Authoring Software Parameter Type	●	●		2
6	Installation Description				
a.	Supplier	●		●	2
7	Product Description				
a.	Asset ID, Object ID or System ID	●	●		2
b.	LOD	●	●		2
c.	Manufacturer or Producer	●	●	●	3
d.	Model Number, Model Type or Product Series	●	●	●	3
e.	Note or Comments	●	●	●	3
f.	Product Number	●	●		2
8	Technical Description				
a.	Electric Current	●	●		2
b.	Number of Objects or Systems	●	●		2
c.	Typical Flow Rate or Airflow	●	●		2
d.	Voltage	●	●		2

KEY:
Requirement Common in All 3 Cases
Requirement Common in 2 Cases

From the analysis in Table 4.2, although there are a total of 172 information requirement types (Appendix G), only 7 (4%) requirements are common in all cases, and 16 (9%) are common in two cases. The remaining 149 information requirement types are mutually exclusive in one case and identified in one case only. The analysed cases only share 23 (13%) of the total defined requirements. Furthermore, the Product Description property set contains the most commonly defined requirements with 3 properties common in 2 and all cases, respectively. This is followed by the General Classification property set with 4 and 2 properties common in 2 and all cases respectively. In addition, the Technical Description property set has the highest number of defined requirements with a total of 46. This is followed by the Product Description property set with a total of 28 requirement types. These results are shown in Figure 4.2.

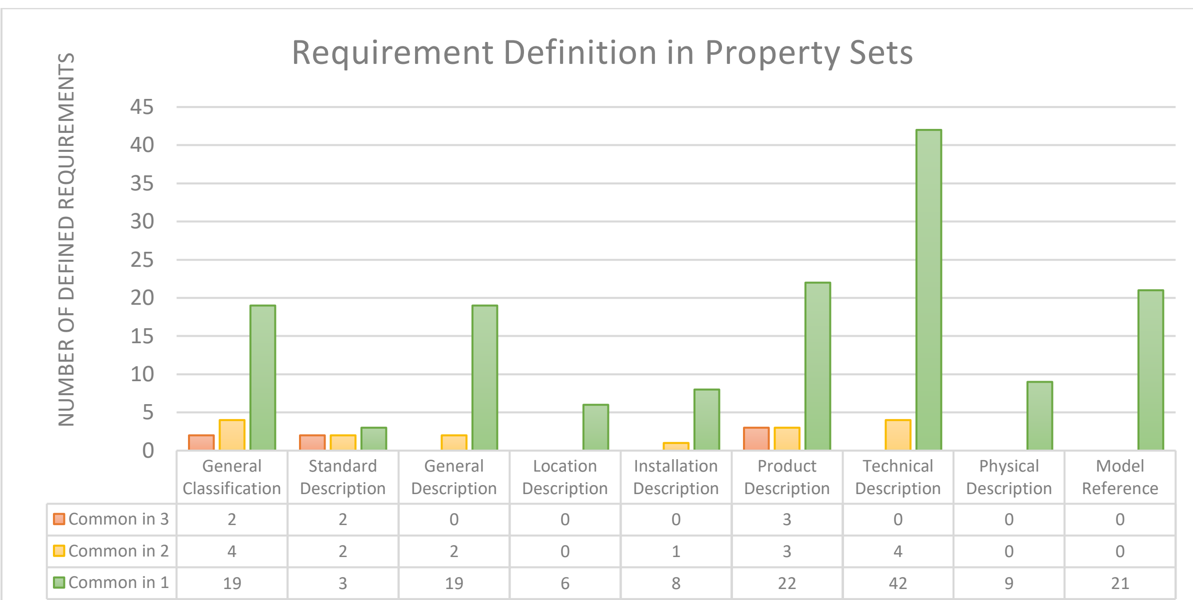
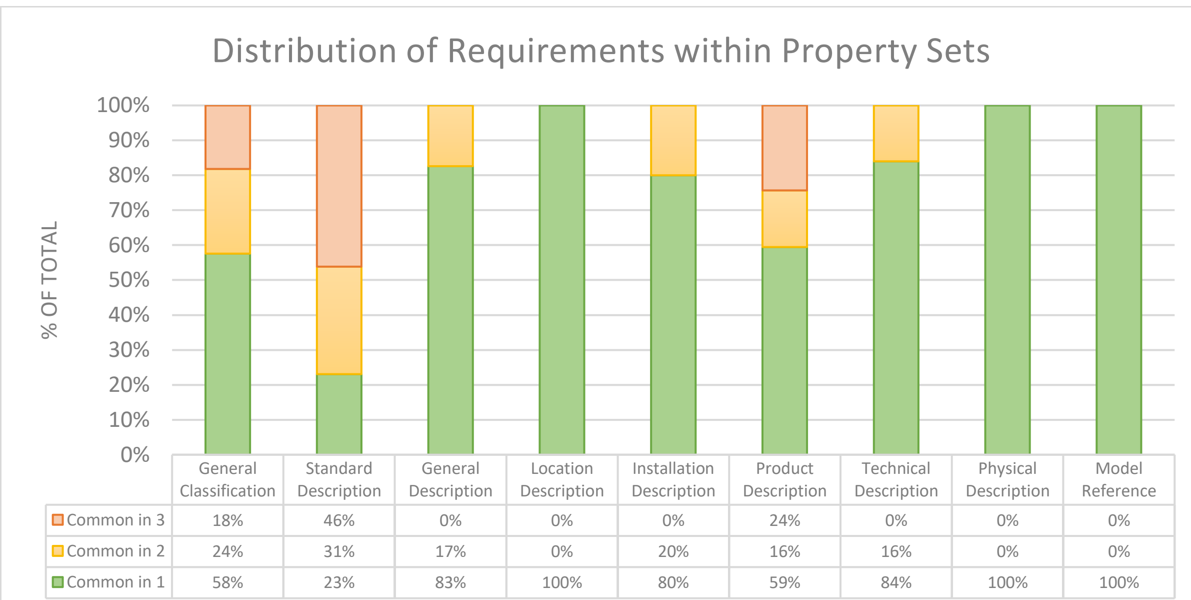


Figure 4.2: Frequently defined requirements in property sets across all cases

The Standard Description property set contains the most shared requirements across all cases compared to the other categories. Moreover, given that System Name (common in 3), Link or Reference to Model (common in 3), Storey or Level (common in 2) and System Code (common in 2) represent a total of 10 entries that are shared respectively out of a group sum of 13 entries. The least shared property sets are Location Description, Physical Description and Model Reference with no shared property. This is shown in Figure 4.3. However, the purpose of this analysis is not to elicit every possible information requirement nor to make statistical inferences but rather to identify the commonly defined requirements within property sets and across all cases. Therefore, these findings indicate that the variation of operational information requirements across all cases result from differing business sector focus. It can be inferred that the main sectors of product or service provision will determine the content of operational information requirements. This will, in turn, enable the organisational BIM-based processes that drive BIM business value. Hence, the results highlight that there is business value for the asset owner to request for the right information for AM tasks in the operations and use phase.



	General Classification	Standard Description	General Description	Location Description	Installation Description	Product Description	Technical Description	Physical Description	Model Reference
Common in 3	18%	46%	0%	0%	0%	24%	0%	0%	0%
Common in 2	24%	31%	17%	0%	20%	16%	16%	0%	0%
Common in 1	58%	23%	83%	100%	80%	59%	84%	100%	100%

Figure 4.3: Frequently defined requirements within property sets

4.5 CONCLUSION

The purpose of the study is to evaluate how asset owners articulate their information requirements for asset operations. It identified important categories and the most frequently requested asset information through a multi-case comparative study. The study critiques the development of BIM-based information requirements, information exchange and business value of operational information requirements. The literature identifies a knowledge gap in the understanding and development of operational information requirements by asset owners.

The findings highlight that there is potential for business value by the client in defining information requirements in line with business needs. The data analysis shows that the Product Description property set contains the most common defined requirements with 3 properties common in two and all cases, respectively. Also, the Technical Description property set has the highest number of defined requirements with a total of 46. In addition, the Standard Description property set contains the most shared requirements across all cases compared to other categories. The study highlights the need to develop a standard meta-requirement template to guide asset owners by providing a general structure for requesting information from the design and construction phases. Furthermore, the study identifies the need to investigate aspects such as change management strategies, BIM-AM systems, systems architecture, network requirements and individual user requirements as factors that would influence the nature and content of operational information requirements.

The findings in this study leads to six main conclusions. First, the study highlights that there are endogenous and exogenous factors that influence business needs which in turn impact on the operational information requirements for BIM-based processes. Second, it may not be possible to develop a rigid list of requirements that are applicable to all asset owners. Thus, only guidance templates and notes can be developed to highlight some categories that will help asset owners to define their data requirements. Third, very few requirements are shared across all cases. Only 7 (4%) requirements are common in all three cases, and 16 (9%) are common in two cases. The results show that only 23 (13%) of the total defined requirements are shared in two or more cases. Fourth, there are varying information requirements across all cases, which results from differing business needs. Fifth, it is clear that operational information requirements are highly connected to business needs. Therefore, the business sector of the asset owner has a clear relationship with the nature and type of information needs for BIM-based processes. Finally, in terms of developing the BIMAsset VRM, the findings in this chapter have indicated that information requirements impact BIM-based processes and underscore the significance of incorporating an element in the BIMAsset VRM that covers the requisition of operational information requirements for BIM-based processes. In conclusion, asset owners need to understand their business needs in relation to their business requirements to be able to derive value from BIM-based processes.

4.6 CHAPTER SUMMARY

This chapter focuses on addressing the existing knowledge gap in relation to the development of BIM-based operational information requirements in the AEC industry. It studies the strategies and the most common operational information requirements by asset owners for BIM-based processes using a qualitative multi-case study approach. Interviews and content analysis are the research techniques used to collect and comparatively analyse the operational information requirements of three asset owners. The findings in this chapter reveal that operational information requirements are strongly related to business needs and that it is not possible to develop a rigid list of requirements for asset owners, but rather some templates to help them define their data requirements. Also, out of a total of 172 analysed operational information requirement types, only 7 requirements are common in all cases, and 16 are common in two cases which represents a total of 4% and 9% respectively. This study identifies three different strategies for operational information requirements; '*Co-development*', '*Environment of Care*' and '*Data Ambassadors*'. Furthermore, this chapter highlights endogenous and exogenous business-level factors that impact on the definition of operational information requirements. Also, this chapter provides templates to help guide asset owners when defining their data requirements for asset operations in order to derive BIM business value (Appendix H, I and J). Finally, the findings in this chapter underscore the significance of incorporating an element in the BIMAsset VRM that covers the requisition of operational information requirements for BIM-based processes.

CHAPTER 5

BUSINESS VALUE OF INTEGRATED BIM-BASED ASSET MANAGEMENT

UNIVERSITY OF LIVERPOOL

5.0 BUSINESS VALUE OF INTEGRATED BIM-BASED ASSET MANAGEMENT

5.1 CHAPTER INTRODUCTION

This chapter sets out the study in relation to Research Objective 2: To investigate and identify the strategies and techniques of how asset owners can integrate BIM with AM systems and the business value to be derived from such integration. This chapter seeks to address one of the research gaps identified in Chapter 2. That is, the lack of understanding regarding techniques for integrating BIM-AM systems during asset operations. In order to address the research problem, there is a need for a social and technical approach. The social aspects to cover change management, stakeholder management and performance management. The technological aspects relating to the setting up of BIM and AM systems effectively in order to derive business value. Effective AM refers to having processes that support the appropriate management of resources including having the required information, at the right time, in the right place, and in the right format for asset managers to achieve business objectives. Currently, the BIM and AM systems are not able to handle data well because they have not been set-up correctly to perform the functions required by the users. This may be due to the lack of awareness from the users and/or difficulty in using the systems. A single case study is adopted to achieve the research objective of identifying techniques for integrating BIM-AM systems during asset operations. The rationale here is that for there to be any business value in BIM-based AM processes; the asset owner needs to understand how effectively set up the management and technical systems. Therefore, there is a need to investigate aspects such as change management strategies, BIM-AM systems, systems architecture, network requirements and individual user requirements as factors that would influence the attainment of an integrated BIM-based AM system by an asset owner. The importance of this chapter with respect to the development of the BIMAsset VRM is that it provides a better understanding of the justification that was made by the researcher for each of the identified elements and sub-elements. These findings are discussed and theoretically validated in Chapter 9.

5.2 RESEARCH JUSTIFICATION

Increasingly, the AEC industry is tasked with the manufacture, collection, and utilisation of data for critical decision-making on assets. The demand for more interpretable asset data by public and private sector asset owners has been on the increase, with many taking on the initiative to implement BIM in the lifecycle of their investments (Love *et al.*, 2013). Aside from data, the utilisation of BIM in AM has also transitioned from the use of BIM as a software to an AInfM system (Love *et al.*, 2013). All these changes are happening as a result of the paradigm shift in the perception of AM by asset owners from necessary maintenance of assets to asset optimisation.

BIM is a methodology that can assist asset managers in managing their portfolios efficiently and effectively. However, the integration of BIM with AM systems, the management processes, strategies and protocols continue to present a significant challenge for BIM implementation across building lifecycle phases (Jupp, 2013). The slow adoption of BIM in AM may be as a result of the nature of BIM, which may be more suited to the design and construction stages. Also, another factor is the seeming complexity of utilisation of BIM for the operations and use phase. The overcoming of these barriers and adoption of BIM will provide the opportunity for asset managers to integrate all the disparate silos of asset information contained in different systems into a federated information model that will facilitate easy access and analysis.

For most asset owners, AM tasks are essential to their business processes. As such, asset maintenance forms part of the strategic business objectives as a result of asset maintenance data that is linked to other strategic systems within the business for asset planning and AM tasks. These organisations rely on structured and trusted data for critical decision-making (Brous, Herder and Janssen, 2015). Generally, it is a reality that most organisations generate far more data than they could possibly use; yet at the same time, they do not have all the data they actually need (Lin, Gao and Koronios, 2008). The challenge for asset owners is in having streamlined data infrastructures and policies, which will deliver the needed high-quality and up-to-date data for AM business processes and critical decision-making. Asset managers have attempted for many years to create AM systems which produce quality data but end up having outputs that are embedded with significant amounts of meaningless data or missing the required information (Lin, Gao and Koronios, 2008; Brous, Herder and Janssen, 2015). Public sector organisations are facing increasing challenges in the management of their assets, and many owner-operators are looking for ways to optimise their assets in order to improve the efficiency of their AM processes through data-driven decision-making (Brous, Herder and Janssen, 2015).

The purpose of this chapter is to investigate and identify the strategies and techniques of how asset owners can integrate BIM with AM systems and the business value to be derived from such integration. This study analyses the processes of a large owner-operator organisation in the UK that utilises BIM in AM tasks. Also, it demonstrates how asset owners can identify what information needs to be captured from physical assets towards BIM-based integration. Furthermore, it can be said that most asset owners do not understand how to go about the whole process of integrating BIM-AM systems in order to derive real business value from BIM-based processes in AM (Jupp, 2013; Love *et al.*, 2014). Hence, the need for further research.

5.3 CHAPTER 5 – DETAILED METHODOLOGICAL APPROACH

This chapter aims to investigate and identify effective techniques and strategies for integrating BIM and AM systems, including the business value that may be derived from such integration. The study addresses the following research questions:

- What are the techniques and strategies of streamlining AM systems for BIM-based integration?
- What information should be captured from physical assets towards BIM-based integration and how?

5.3.1 RESEARCH METHODS

The case study involves a large retail organisation in the UK to investigate how asset owners can formulate and implement a strategy to streamline their AM systems within BIM. The study also investigates the business value derived through BIM-based processes and the challenges experienced by the asset owner. The owner-operator organisation does not want to be identified, and so will be referred to as 'Company D' in this study.

The study focuses on the AM activities carried out by the Estates Department under the Property Division in Company D. This department is responsible for maintaining over 2,000 built assets at the strategic level. These comprise of trading and non-trading assets owned or managed by Company D. The department is also responsible for identifying strategic approaches, technologies and innovations for implementation within the organisation. The department also liaises with the FM department within the organisation to manage the physical assets at the operational level.

The study adopts a case study strategy. This helps provide an in-depth investigation into particular instances of BIM-AM systems integration. Furthermore, this study adopts an operational construct sampling technique which is a typology of purposive sampling for the identification of the case and selection of participants for data collection. Furthermore, the study partly utilised snowball sampling to explore the researcher's network in order to identify and select the case study, including the participants (Patton, 2002). This strategy is used because of the rare cases of operational BIM implementation in AM. The criteria used for selecting participants are:

- Participants have an advanced level of knowledge and understanding of BIM in AM.
- Participants are senior staff of the owner-operator.
- Participants are senior staff of the consulting company engaged for the project.
- Participants are key stakeholders in the project.
- Participants are high-level decision-makers in the project.
- Participants are involved in every process of strategic and operational decision-making.

The above criteria are designed to ensure that the selected participants cover the stakeholders responsible for developing and executing the organisational strategy aimed at integrating BIM-based AM systems in Company D. The type of validation carried out in this study refers to participant validation. Participant validation is also conducted on the collected data in order for them to comment on and correct it in order to validate it (Saunders, Lewis and Thornhill, 2016). This process was carried out by the researcher by sending the analysed results to the participants for authentication of the accuracy of data presented in this study. As such, the interview transcripts and analysed results were adjusted in line with the comments of the participants in order for the study to accurately represent their views and responses based on the interview questions asked.

The literature review helped to explore existing research on BIM and data governance in AM (Section 2.4.3, 2.4.4, 2.8 and 5.2). Furthermore, the case study research investigates the techniques and strategies of integrating BIM-AM systems in Company D. The review of literature is conducted to identify relevant studies related to data governance and asset management practices. Also, key aspects related to this subject matter such as governance, change management, performance management and stakeholder management are reviewed. The study identifies frameworks and methodologies developed by other studies within the area of BIM implementation in AM. The study specifically selects the governance framework by Love *et al.* (2014) as a guide to understanding the phenomena during thematic analysis. The second phase has two main activities; they are: interviews and archival analysis. Interviews are used to gather in-depth information on the processes involved by Company D in integrating BIM with AM systems. The purpose of the interviews is to extract qualitative descriptions of organisational strategies, business process re-engineering techniques, change management strategies, business value and challenges of implementing BIM-based processes in AM. Furthermore, archival analysis is carried out to identify the current organisational strategy of Company D for transitioning into BIM-based workflows. A number of project documents, including the discovery workshops approach and strategic implementation guide, were also reviewed.

5.3.1.1 RESEARCH PROCESS: DEDUCTIVE REASONING SRQ-2

This section presents the methodological process of this part of the study. Here, deductive reasoning is utilised in SRQ-2 to understand and document key phenomena regarding data governance, change management, performance management and stakeholder engagement in relation to BIM-based AM. This aspect of abductive inference of the PRQ pertains to the identification of effective strategies for integrating BIM and AM systems. The research progression is shown in Figure 5.1:

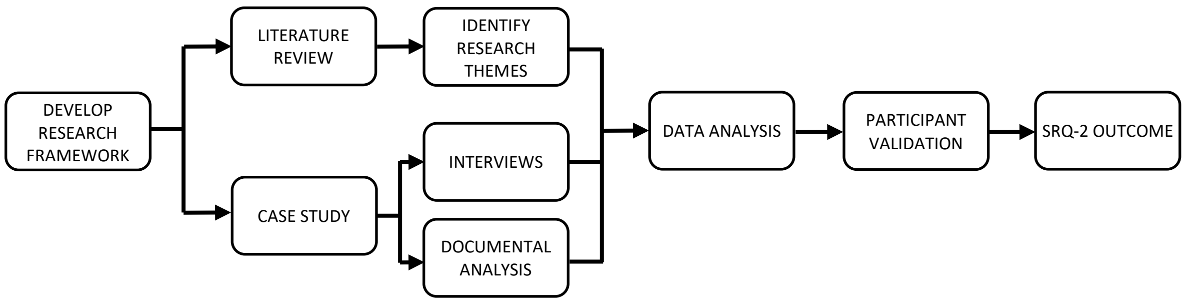


Figure 5.1: Deductive reasoning SRQ-2

5.3.1.2 DATA COLLECTION AND ANALYSIS

The study adopts a qualitative approach to data collection and analysis. Qualitative research methods elicit information on people's experience, feelings and priorities (Saunders, Lewis and Thornhill, 2016). Furthermore, the qualitative approach allows researchers to probe the research questions with the aim of gathering information (Fellows and Liu, 2015). The study utilised qualitative methods in order to document the strategic approach for the standardisation of the asset register, asset hierarchy, asset information model and business processes for streamlining AM systems towards BIM-based integration. Primary data is collected through interviews and archival analysis. Interview data is transcribed and analysed using the NVivo™ software (Bazeley and Jackson, 2013; Saunders, Lewis and Thornhill, 2016). The study utilised thematic analysis during data analysis. Thematic analysis is a technique used in qualitative research for identifying, analysing and reporting themes or topics within data (Boyatzis, 1998). Initial themes are established from literature, which guided the various aspects of data analysis for this study. That is: governance, change management, stakeholder management and performance management. The study utilised the technique of coding for easy analysis of data and linkage to the study themes. Coding in qualitative analysis is a method of indexing data to facilitate easy retrieval and analysis (Boyatzis, 1998). The study focuses on Company D's organisational BIM-AM strategy, BIM-AM implementation strategies, BIM-AM implementation process, BIM-AM business value and

BIM-AM barriers. These notations are developed as part of the thematic analysis done in the literature review phase. The themes informed the development of interview questions for data collection. The interview questions guided coding and categorisation of data during analysis. The study characterised the themes into codes, categories and notations, as shown in Table 5.1:

Table 5.1: Shows data themes, codes, categories and notations

S/N	THEME	CODE	CATEGORY	NOTATION
1	Governance	Data Governance Strategic Governance	Section 5.4.5	Governance
		Data Governance Strategic Governance	Section 5.4.6	Asset Register
		Strategic Governance	Section 5.4.7	Asset Hierarchy
2	Change Management	Organisational Strategy	Section 5.4.2	BIM-AM Strategy
		Operational Strategy	Section 5.4.3	BIM-AM Implementation
		Systems Strategy	Section 5.4.4	BIM-AM Systems Architecture
3	Stakeholder Management	Stakeholder Engagement	Section 5.4.3	BIM-AM Implementation
4	Performance Management	BIM Value Management Process	Section 5.4.3.3	BIM-AM Value Realisation
		BIM Business Value/ Operational Merits	Section 5.4.8	Business Value of BIM-AM
		Operational Demerits	Section 5.4.9	BIM-AM Challenges

The thematic analysis process started from the literature review exercise, where four themes were developed: Governance, Change, Stakeholder and Performance Management. Additionally, these thematic classifications guided the development of interview questions for the study. The thematic categories shaped the topical points of which the interview questions were based upon. Furthermore, the thematic categories guided the establishment of codes during the analysis of the qualitative semi-structured interviews. Thus, similar codes were grouped together into categories and given labels or notations in the presentation of results in the following sections.

5.4 RESULTS: CASE STUDY: BIM-AM SYSTEMS INTEGRATION AT COMPANY D

The results presented in this section and sub-sections are from the findings of the semi-structured interviews and archival analysis.

5.4.1 INTRODUCTION

Company D as an asset owner and owner-operator has set out on an initiative to implement BIM-based processes in their organisation. A BIM-based process refers to an activity or a set of activities that rely on the use of intelligent data generated by a BIM system together with other Digital Information Technologies (DIT) to be able to conduct critical asset assessment that informs contract management, lifecycle management, maintenance management, work-order management, value realisation management or other use in order to achieve business objectives. This action aims to position Company D as one of the leading owner-operators to utilise BIM in AM processes in the UK. The utilisation of BIM in their AM processes will improve efficiency and give the organisation an advantage over their competitors. However, BIM has the potential to make processes efficient if only it is implemented correctly. This transformation enabled documents and data to be accessed from any facility through a data infrastructure that is supported from multiple locations. These processes are expected to improve information delivery within Company D for critical decision-making and better management of its built assets.

Company D had engaged consultants, contractors and their supply chain who have the ability to work with collaborative industry standards and intelligent object modelling. Also, they engaged consultants to advise on best practices and standards that will contribute to success in implementation. Thus, appraising asset data architecture for integrating new systems and planning change management activities in line with the organisational goals.

Company D started the journey by modelling its assets and reaching BIM Level 2. At BIM Level 2, they have been able to meet each project’s requirements by adhering to the standards set by the UK Government in the creation of a federated model, collaborative working, and information exchange methods for their newly built assets. The plan is achieved by the establishment of organisational processes that facilitate data to be exchangeable for construction, fabrication, and FM purposes, whilst enhancing lifecycle management and open collaboration. They plan to fully integrate their data and systems architecture for optimal information management and data delivery. Currently, Company D have modelled about 100 of their new assets and are still implementing 3D-BIM for new developments and major upgrades. However, there has been a shift in strategy, and Company D is now focused on realigning AM processes to BIM-based processes using 2D object-based CAD. This strategy was adopted predominantly for existing buildings because of the high cost of digitising the built assets in 3D compared to the achieved business value.

Initially, Company D viewed BIM from the perspective of 3D Modelling of their assets, but the organisation's focus gradually shifted to building information management. That is, looking at how information from their assets can be sourced, managed, stored and retrieved efficiently for AM tasks through BIM-based processes.

5.4.2 BIM-AM STRATEGY

In formulating an implementation strategy, Company D developed a three-part rationale for their BIM-AM based integration. The plan of action set out to establish a system that could find asset information within the organisation and across different systems quickly, accurately and completely through better management and continued development of information and systems. Company D was able to develop maturity levels for their data and systems development, but ultimately, the vision is to have single-source data for their entire AM processes. Company D is currently working with all departments to remove data duplications across their systems and ensure that every asset has the same unique ID across the database. As the maturity grows, it is expected that for all their assets, the central AM system would generate the asset name and numbers from a single source.

The BIM-AM strategy for Company D consists of four components, which are: the right systems; defined data; culture and training; and the right process. The selection of the right systems for AM tasks is vital to the entire process. These systems will provide a platform for data exchange within the organisation. Defined data refers to the processes involved for the organisation to identify and understand the data requirements for each department and user in the whole organisation. Culture and training involve the continuous capacity development of the users and the change management strategies utilised for effective implementation. The right processes in this context represent the entire business processes re-engineering activities for enhanced efficiency. In general, it is expected that this strategy will provide Company D with a mechanism that will deliver three things for the organisation – a filing cabinet, a database and a process manager (Figure 5.2). That is, a data structure to organise their data, a secure and efficient system architecture to store it, and a structured workflow to guide its internal processes.

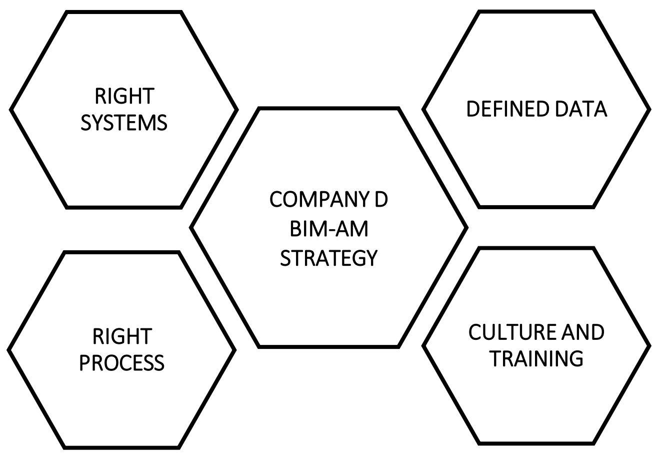


Figure 5.2: Company D BIM-AM strategy

5.4.3 IMPLEMENTATION OF BIM-BASED PROCESSES IN AM

The implementation process follows the strategy formulation, and one of the first activities that Company D conducted was to develop a set of Plain Language Questions (PLQs) to help drive their BIM-AM strategy. These PLQs ask the very basic queries like: '*Have we got any…?*'; '*How many…?*'; '*Where are …?*'; '*When is the…?*'; '*Is there…?*'; '*Which…?*'; '*Who is…?*'; within the organisation.

Furthermore, Company D developed cartoon characters that asked the same PLQs for their workshops to aid understanding. These characters depicted the typical working environment in Company D, interacting and conversing in plain language, asking and answering basic queries.

The next step Company D took was to develop organisational standards for data exchange and information delivery. Company D developed their organisational standards based on BS:1192 (BSI, 2016), PAS:1192-2 (BSI, 2013), PAS:1192-3 (BSI, 2014a), BS:1192-4 (BSI, 2014b), and PAS:1192-5 (BSI, 2015). These standards govern data use at Company D.

The implementation process involved three phases; BIM-AM strategic stage, BIM-AM implementation stages and BIM-AM value realisation stage. As an implementation activity, the discovery exercise is a stand-out activity where the organisation investigates and understands the daily tasks of its employees and various departments together with their objectives and needs. This is a key process as it helps define all subsequent activities involved in the implementation process.

5.4.3.1 BIM-AM STRATEGIC STAGE

The strategic phase involves four essential processes, which are; discovery phase, outline business case, proof of concept and full business case (Figure 5.3).

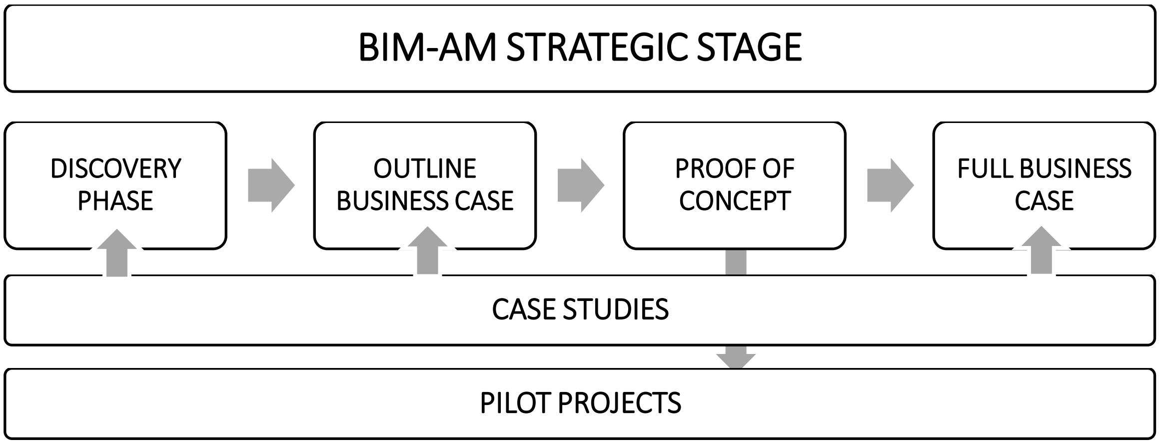


Figure 5.3: The processes involved in the strategic stage

The implementation process and strategic stage starts-off with the discovery exercise. The discovery methodology adopted by Company D essentially involves talking to users and asking the right questions about their data requirements for daily tasks. This process aims to identify the information needs of users and eliminate the duplication of tasks within the organisation. The process enables the team to investigate deeply as to what data source provides information for which task, the different types of processes involved in executing a particular task, and the outcomes that are intended. This is usually a one-off process for all AM-personnel and a repetitive process for every department. Thus, while conducting the discovery across departments, any incongruity observed by the team is turned into a case study. The full list is filtered, and a shortlist is drawn for pilot projects.

The discovery exercise involves five key components, which are; desktop discovery, stakeholder engagement, stakeholder discovery, stakeholder workshops, and technical and data source discovery (Figure 5.4). Desktop discovery involves the review of publicly available documents and information. Organograms, strategic documents and business processes are studied by the implementation team. This activity is carried out to fully understand the nature of the organisation. Stakeholder engagement concerns the process of liaising with other departmental teams at Company D, in order to communicate on the overall vision for the information management processes, the associated impacts to business processes, and the proposed data governance structures. This activity also focuses on the needs and targeted business value for the BIM-based processes. Stakeholder discovery involves the capturing of high-level systems and process information in Company D. This process will identify key personnel that are responsible for the capture, production, utilisation and transmission of information within the organisation for the effective management of assets. Managers will be called in to participate in identifying and classifying key activities and subsequent recommendations for potential improvements. Stakeholder workshops are conducted to identify users' perceptions of the current information flow processes, which will guide the roadmap. Work shadowing is also conducted at this stage. The main purpose of this activity is for external observers to identify any obstacles and workarounds that are not easily identifiable during the interview workshops. Technical and data source discovery involves the development of high level '*as-is*' process maps of the current systems used by departments across Company D. These documents will be developed into process maps to fully understand the system intricacies and data flow between users, systems and departments. All the five components of the discovery exercise mentioned above probe four main elements organisation-wide. These are the data sources, processes, systems and users' requirements.

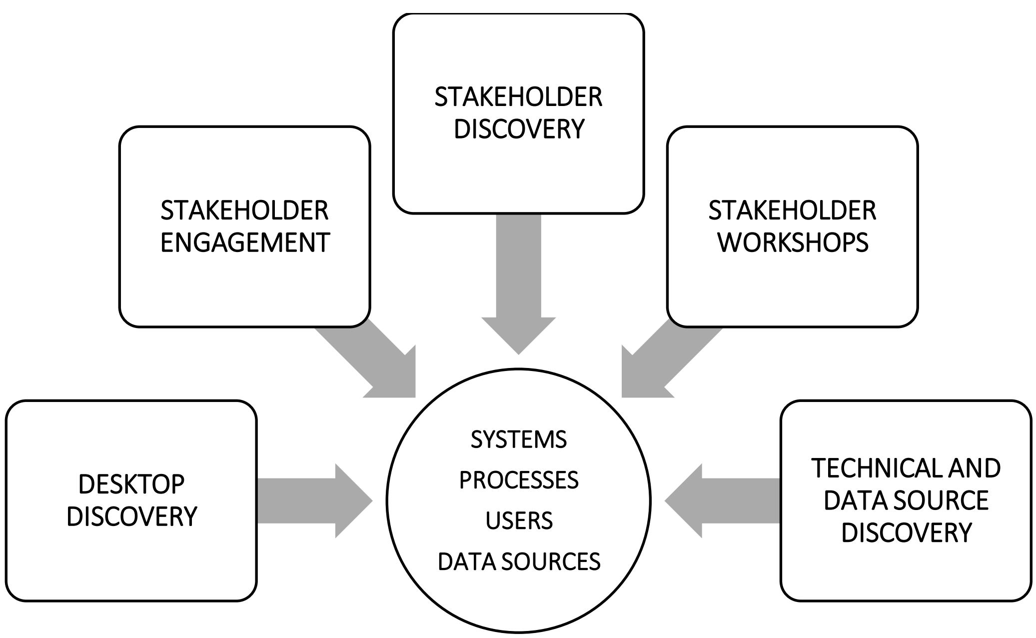


Figure 5.4: The key components of the discovery exercise

The next phase after discovery is the development of the outline business case. The organisation prepares the business case on the basis of its expected commercial business value of adopting BIM-based processes. At this level, the organisation can appraise preliminary results of the value realisation activity conducted on the identified case studies and pilot projects from the discovery exercise. These benefits will then be fed back into the outline business case.

Following the outline business case is the proof of concept. In this context, the tasks carried out involve the testing of BIM in AM processes with the aim of establishing viability, isolating technical issues and identifying indicators that may guide implementation. The information derived from the discovery exercise will help shape the proof of concept that will drive the experimentation in pilot projects. The full business case involves the preparation, acknowledgement and approval of the developed business case. This is based on the discovery exercise, case studies and pilot projects. The business case is finalised by the implementation team and signed-off by the board.

5.4.3.2 BIM-AM IMPLEMENTATION STAGE

Many asset owners that aim to implement BIM often start from this stage and totally ignore the strategic phase. Usually, they make the BIM investment and then work-out how the existing systems will be configured. Company D had developed and implemented a strategic phase that will enable the organisation to prepare properly for the implementation stage. At this stage, the lessons learnt from the pilot projects help guide implementation. The implementation stage consists of three main processes; detailed design phase, mobilisation phase and transition phase (Figure 5.5).

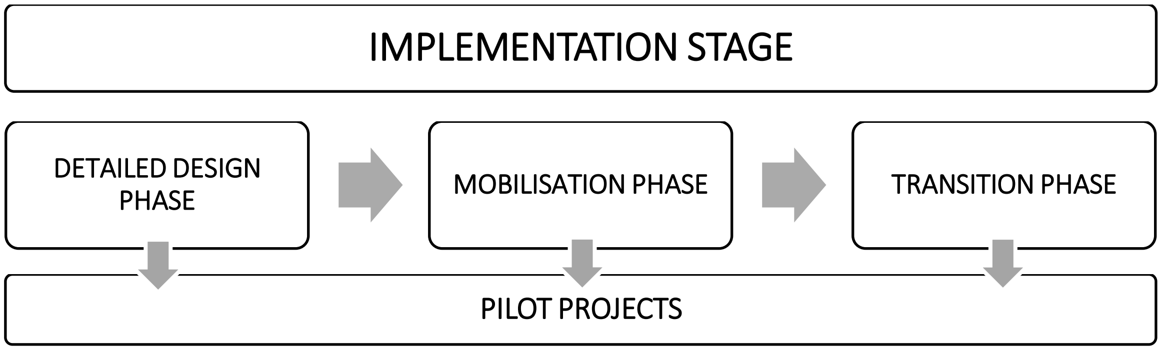


Figure 5.5: The processes involved in the implementation stage

The detailed design phase involves the creation of artefacts, development of documents and configuration of systems for the BIM process as identified in the strategic stage by the implementation team. The requirements from the discovery exercise are transformed to an organisational system design document, which appropriately describes the design of the proposed BIM-AM system. It describes details of the systems, the interaction between each component, the interfaces, and its functions. Furthermore, the hardware and network approaches for the solutions from the business case are developed. As the pilot projects carry on, Company D increasingly learned from them, and they fed-back to the process during the development of detailed designs for the remaining case studies.

The mobilisation phase includes the processes of putting in place technical and organisational mechanisms for the deployment of BIM-AM systems at Company D. Here, Company D gradually introduced the new BIM-AM systems within the organisation to be able to control the level of disruptions to activities. From, this point, the organisation starts switching to the new systems for AM tasks.

At the transition phase, Company D moved from the old systems to the new systems. Here, Company D observes the effect of the changes to the system and how users adapt to the new processes.

5.4.3.3 BIM-AM VALUE REALISATION STAGE

The main purpose of this phase is to realise value. An organisation should not develop a business case and be unable to measure the business value it contributes. This stage is important to the entire implementation process because this is where the organisation establishes project success. The business value realisation phase involves two basic processes; result appraisal and value realisation (Figure 5.6).

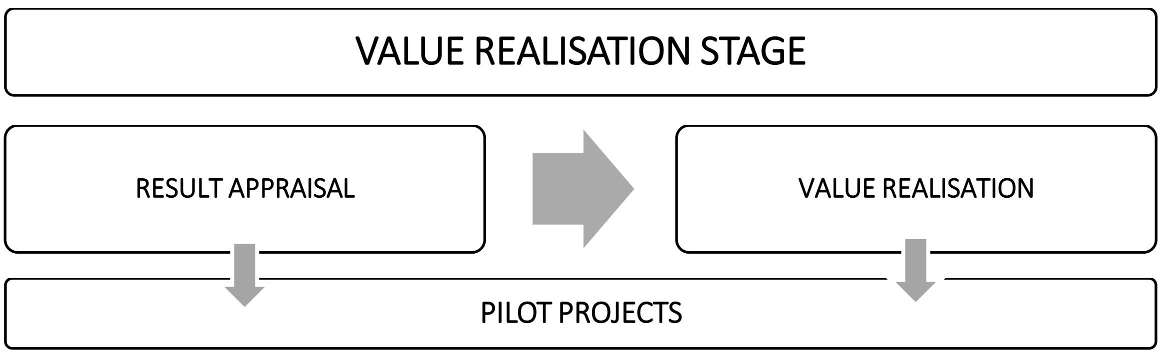


Figure 5.6: The processes involved in the value realisation stage

Firstly, Company D had to go back to the users to observe and ask how different the processes were in order to identify the desired and undesired effects. The outcomes of change brought about by BIM in relation to business outcomes were observed and evaluated by Company D. These were done in the form of questionnaire results to track the reduction in mistakes and referring back to the case studies that were developed during the discovery exercise. The outcomes are compared to the case studies for result evaluation.

Finally, the business value is realised through established KPIs. Another process used by Company D, which is the deployment of questionnaires to appraise users' perception before and after implementation. The outcomes are compared for any positive or negative variance. The entire results established at this stage are archived by Company D. Value realisation encompasses the acknowledgement of the value derived from the BIM-based processes.

5.4.4 BIM-AM SYSTEMS ARCHITECTURE

The systems architecture in Company D is unique with a variety of platforms for executing the multifarious business processes, as shown in Figure 5.7. For AM processes, Company D utilises an interface for case and task management with automatic routing and escalating important events or tasks '*System A*'. This is the main repository that generates and holds the master asset ID, from which the other systems obtain information. Also, Company D uses a property, asset, facility and financial management platform in the operation of its asset portfolios '*System B*'. This is used to monitor assets, manage compliance with regulations, streamline invoicing, and manage asset interventions related to rates, rents and leases. Furthermore, Company D deploys an FM system '*System C*' for the day-to-day operation of their assets. This system holds most of the information in the asset register. Also, Company D utilises an information management and project extranet system '*System D'*. This provides a platform for securely storing and managing the project asset data. Finally, '*System E*' which is essentially the use of spreadsheets, to manage data from external sources for the purpose of centralisation.

For BIM-based processes, Company D utilises a 3D modelling software '*System F*'. Also, Company D uses a computer-aided design software '*System G*' for the development of 2D object-based CAD in their BIM processes. '*System G*' is operated with a plug-in '*System H*', which is essentially a placement tool and ensures standardisation of asset floor plans. '*System I*' is the CDE. Also, Company D utilises a construction collaboration platform called '*System J*'. This is a web-based platform that helps bring BIM-based data into one platform. This enables Company D to plan, implement and deliver fully integrated BIM-based build programmes.

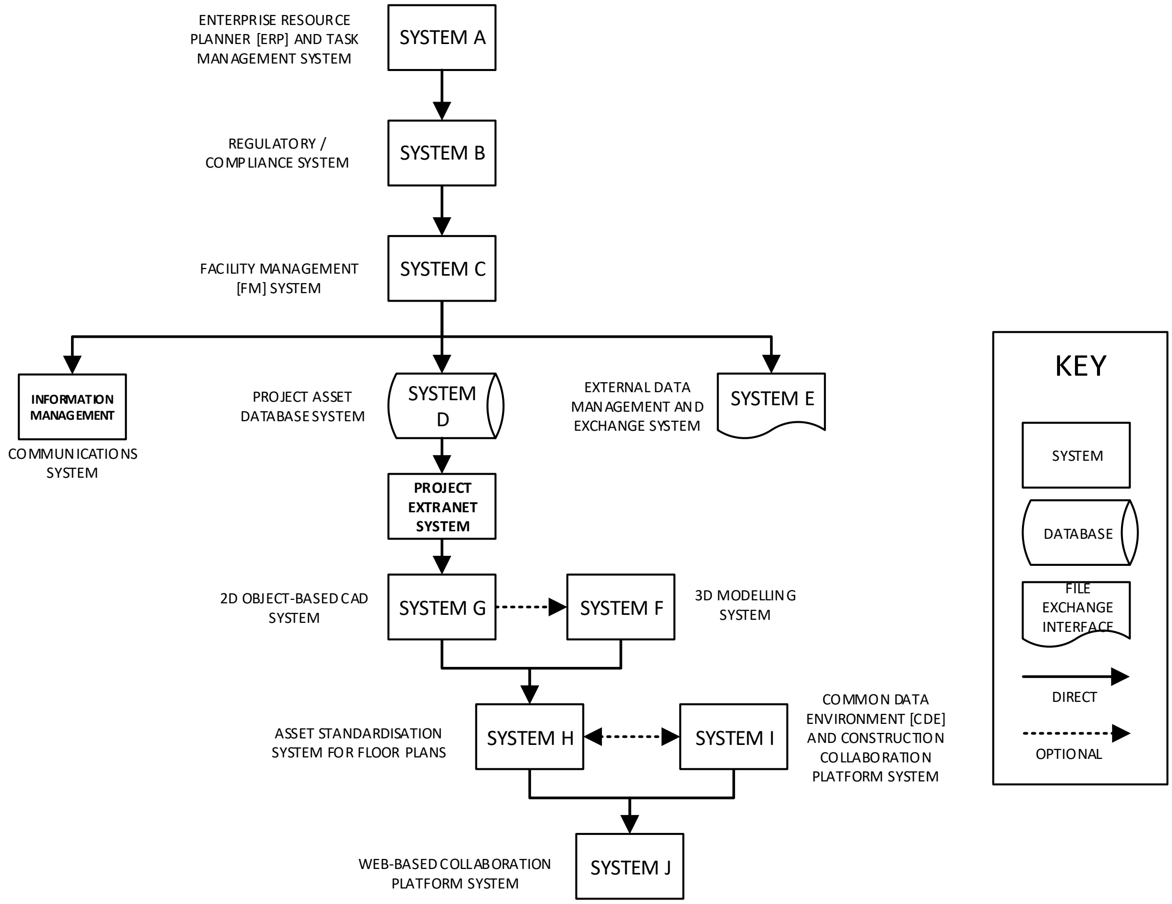


Figure 5.7: Systems architecture at Company D

5.4.5 GOVERNANCE

The philosophy of data governance in Company D is ensuring that users are engaged continuously throughout the change process of adopting new information management processes, including process modifications relating to how information is created, stored and shared. The standards mentioned in Section 5.4.3 were used to develop the new approach of information management, document control, data governance and data auditing in Company D.

Information transaction standards were developed to guide the new information architecture for BIM-based AM processes. These standards have defined data structures, picklists, find fields and classifications to ensure that an asset is captured and referenced consistently in all systems across Company D. Assets are labelled in a systematic reference to eliminate ambiguity organisation-wide. One of the activities performed was to establish a format for the allocation of a unique identifier for every asset across Company D. Also, a file naming code sheet was introduced for asset naming and floor numbering systems during project execution and ensuring that the supply chain reference the same asset space using the unique ID allocated by Company D. This document helped in standardisation, version control and to ensure every user calls an '*apple*' an '*apple*' right through the entire process.

Another key aspect to data governance is the centralisation of data, which Company D associates with data completeness. Company D realised that centralisation of data is important, and the quality decisions on assets can only be made if the data available is complete. Company D found out that individual data managed offline by users may be of benefit to their colleagues for executing other tasks within the organisation. Currently, they are now making efforts to bring together all data in one centralised location.

Furthermore, another aspect related to governance is the technical aspect of systems development synchronisation. This activity was done through the utilisation of Application Programming Interfaces (API) to make AM processes more efficient in Company D. These sets of definitions, tools and protocols help connect the various databases to enable reporting across them. This involves defining processes and making sure that other remote systems get updated with the right information, at the right time, with no duplications.

Lastly, another aspect related to governance is the organisational structure. There is a department responsible for regulating the data standards and practices for data governance at Company D. It is a department under the property division. This department also liaises with the FM team within the organisation for the effective management of assets within the organisation.

5.4.6 ASSET REGISTER

Company D has a standard process for developing the asset register, which is essentially a property list. The register has many classifications based on ownership, asset type, location and asset function. Company D has a standard process at key milestones of every project to the point of handover. The processes start with the client brief to the point of obtaining planning permissions. It is at this point that the organisation decides on whether the asset will be built. In general, the entire processes adopted by Company D are in line with the RIBA plan of work. All asset information collected right through the asset development process is stored in 'System A'. This system is a central repository that holds everything and manages the process of asset development up to the point where an asset is assigned a unique ID.

Essentially, when the asset obtains planning permission, it gets a unique ID. This ID will be based on the asset classification in the asset register. This classification generates many other individual data for different departments in the organisation, which is stored in '*System C*'. The various departments then continue their activities to develop the asset register further. For example, the FM team will populate the built asset register with other physical assets such as furniture, equipment, fittings and fixtures. The process is usually done with stickers and a handheld scanner to take inventory for the asset register.

In the asset register, most assets have an asset location ID, which is the classification of a group of assets at a particular site. This unique ID reflects the hierarchical classification of the asset, which is usually based on its function, type and location. Furthermore, other details are recorded in the register, which include functional areas of the asset such as sales floor, concessions, warehouse holding and customer facilities areas. This activity is done so that the business is able to track the unusable areas in all of its assets from the asset register.

Another system, '*System B*' holds the data for the non-trading assets in the organisation. '*System A*' is linked to '*System B*', which is an outsourced property management solution that is managed by a third party. This system looks after rates, rents and everything else that is non-trading. '*System C*' also holds the register for the remaining physical assets. These three systems together give the full asset register for the organisation (Figure 5.8).

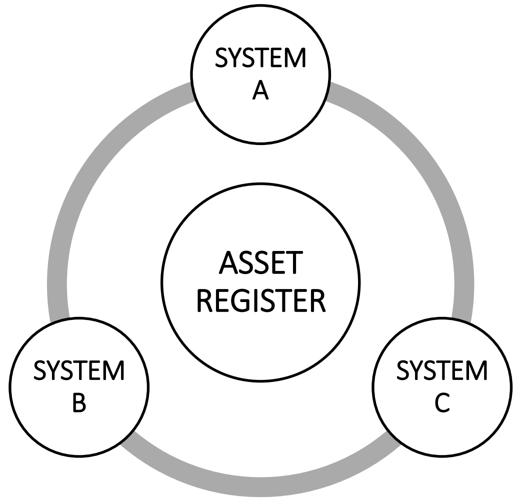


Figure 5.8: Systems that make up the asset register at Company D

5.4.7 ASSET HIERARCHY

Company D has developed an asset hierarchy that goes from the general to the specific. The major classifications are; business zones, business region, location, assets, levels, rooms and spaces, and components (Figure 5.9). The asset is given a particular reference for any of the classifications it represents. The business zone is the defined operational zones within the organisation. The business region is a collection of sites within a business zone. The location is the particular site where the asset is situated. The asset represents the type of building and the function that it performs. Levels within the asset hierarchy show the number of levels contained in an asset. This deals with occupancy and space management. Rooms and spaces represent the individual spaces within an asset. This concerns the types of areas within the asset, such as customer facilities or trading floor. Components are the physical assets that have been installed within a particular space. The component type and other parameters are recorded at this level. The hierarchy is defined for every asset and corresponding areas and components within them.

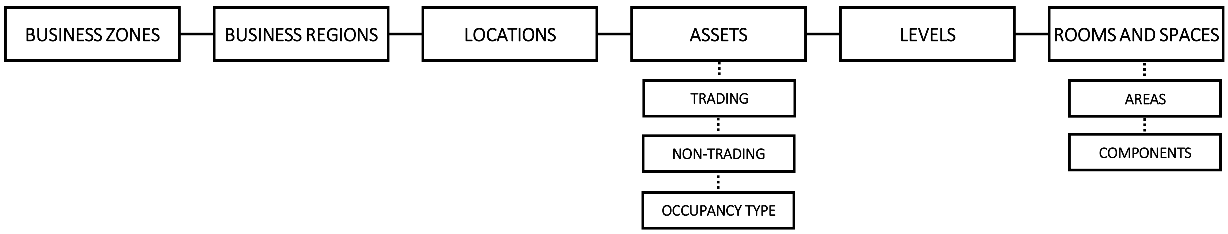


Figure 5.9: Asset hierarchy structure of Company D

5.4.8 BUSINESS VALUE OF BIM-AM SYSTEMS INTEGRATION

For the AM processes, BIM has enabled Company D to effectively manage its asset information through better information management, document control, governance, and auditing. Another benefit derived is the standardisation of processes organisation-wide. The utilisation of '*System J*' provided a platform for Company D to manage the specifications, standardisation of components and room datasheets.

5.4.9 CHALLENGES OF BIM-AM SYSTEMS INTEGRATION

From the interviews conducted, the following themes are identified as barriers to the implementation of BIM in AM; they are; complexity and cost associated with BIM, the irrelevance of 3D spatial data in AM processes, ownership structure of assets, managing the asset handover process and managing change within the organisation.

5.4.9.1 COMPLEXITY AND COST ASSOCIATED WITH BIM

The respondents highlighted the high cost of updating and maintaining the 3D-Models as a barrier to implementation. It was highlighted that the organisation would have to be sure of the savings to be achieved before they would embark on digitising the existing as-built assets to 3D models. Furthermore, the interviewees indicated that at the moment, they have not found any evidence of real value for converting existing documentation to 3D. Also, the respondents mentioned that maintaining updated as-built 3D models would require a lot of resources and that it would be a huge investment to do the conversions.

The respondents further stated that their initial 3D-BIM approach did not work for them, as the consultants paid a lot of attention to the design and construction models. Essentially, the models contained too much information that they did not need for the purpose of AM tasks. The respondents concluded that currently, there is organisation preference of 2D object-based CAD for AM processes. The availability of 3D-geometric data was an additional benefit to the organisation, but considering the cost, 2D object-based CAD provided better resource efficiency and cost-effectiveness. To support these findings, McArthur (2015) highlights the difficulty associated with digitising as-built assets and the high level of effort required to create new or to modify existing building information models for built assets.

5.4.9.2 IRRELEVANCE OF 3D-GEOMETRIC DATA IN AM PROCESSES

One of the key findings of this study is the assertion by respondents that 3D-geometric data may not be very relevant for AM tasks. The respondents stated that during the process of strategy development, Company D realised that 3D-models were of no value to their operations. Furthermore, the respondents highlighted that what the users needed were asset information on floor plan layouts which could be delivered with 2D-object-based CAD. Hence, the switch in focus by the organisation from 3D-BIM to an information management perspective, which focused more on 2D object-based modelling. Company D derived business value from the use of BIM such as retrieving asset data and product sales visually, but the respondents highlighted that regardless of BIM, they had the capability to evaluate their products' performance data using existing systems, and all BIM contributed was accessing the information visually.

Generally, the requirements for AM tasks are not properly understood at the front end of the project delivery process. As a result, data handed over from the design and construction phases must be filtered down so that asset managers get the data they actually need for their daily work. In line with these findings, Mayo and Issa (2014) suggest the requirement of non-geometric information for business processes in the operations and use phase.

5.4.9.3 OWNERSHIP STRUCTURE OF ASSETS

Another barrier is the ownership structure of assets. Every owner-operator has its unique organisational structure, including its business structure, which determines how assets are owned, operated and maintained. The interviews revealed that Company D did not own some of their assets, as a number were leased or concessioned. This reason alone makes it difficult to implement BIM for those assets as they would not be operating them. Without total ownership of the assets, it may not be of much value for Company D to invest in BIM in those circumstances.

5.4.9.4 MANAGING THE ASSET HANDOVER PROCESS

An important factor that affects the implementation of BIM in AM is the manner in which the handover process is managed. The respondents asserted that updating the as-designed models to include every as-built information required a lot of resources. They also highlighted that the organisation had not put in place any mechanism to validate the 3D models at hand-over stage. In line with these findings, Jupp (2013) suggested a lack of a holistic approach to BIM and lifecycle management which include a lack of procedure for verifying the as-built datasets as a barrier for the operations and use phase. Furthermore, Jupp (2013) highlights the challenges for utilising building information models at handover as a result of incomplete models, lack of verification of models, lack of capture of requirements, knowledge and expertise for the operations and use phase. Also, McArthur (2015) highlights the challenges of handling uncertainty where building documentation is incomplete at handover.

5.4.9.5 MANAGING CHANGE WITHIN THE ORGANISATION

Change management within the organisation is a significant factor towards BIM implementation in AM. The respondents revealed that the organisation experiences some challenges in the consistent management of the roll-out process and adoption organisation-wide. Furthermore, the respondents mentioned that the culture of adoption and change perception of users is an aspect that the organisation is focusing on in order to develop solutions. The interviewees pointed out that some of the solutions were realised from the stakeholder workshops and shadowing activity conducted during the discovery exercise. They further highlighted that since designers at the front end do not understand the nature of activities the asset managers do on a daily basis; the discovery and subsequent recommendations focus on current work issues and proffer more simplified processes that will make AM tasks more efficient.

Consistent with these findings, Jupp and Awad (2017) identify challenges of transitioning from traditional to BIM-based processes as a barrier to implementation. These management shortcomings were also identified by Jupp (2013) stating that the integration and management of processes, technologies and protocols across building lifecycle phases continues to present major challenges to its implementation.

5.5 CONCLUSION

This study explored the strategic and operational techniques of implementing and streamlining BIM with AM systems, and how it can be achieved by an asset owner through a research case study. It describes in detail organisational strategies of BIM-based integration in AM, including the strategic approach and implementation plans. The study also highlights the business value of BIM-based integration in AM, including the business value management realisation process. The findings of this study will help guide asset owners seeking to implement BIM in AM and realise business value from BIM-AM systems integration.

Furthermore, the study confirms that one of the reasons of the slow adoption of BIM in AM is the industry perception of BIM, which is seen as a 3D-model, not as an information model or information management tool. Also, this study clears the misconception of having all asset data in one model or system as a prerequisite for implementing BIM. The information can be in several systems provided that they are all linked. Company D has been successful in implementing BIM and integrating it with their AM systems. For an organisation to be successful in streamlining asset data with BIM systems, the following key issues have to be considered: the development for a clear strategy prior to adoption; connecting the strategy to the business goals. Generally, to overcome BIM adoption barriers in AM, asset owners need to understand their organisational information needs for AM tasks. They also need to understand the type of organisational change required in adopting BIM-based business processes. Owner-operators that have been able to streamline their AM and BIM systems did so through discovery of data needs, development of in-house standards, and continuous improvement of management practices that govern such systems. This also included management activities such as standardising assets within the register with unique identifiers, understanding the business processes and the information needs of users, business process re-engineering, and recommending the right systems to support the digital workplace. Finally, in terms of developing the BIMAsset VRM, the findings in this chapter have indicated that organisational information requirements, strategy, policy and systems architecture impact the execution of BIM-based processes and subsequent value realisation. The findings underscore the significance of incorporating elements in the BIMAsset VRM that cover: (i) the development of organisational information requirements for BIM-based processes; (ii) the development of an organisational strategy for BIM-based processes; (iii) the adoption of suitable BIM standards and policies; and (iv) the development of an effective systems architecture for BIM-based processes.

5.6 CHAPTER SUMMARY

This chapter focuses on the knowledge gap in relation to the techniques and strategies of integrating BIM-AM systems during asset operations. It also seeks to identify how the information is captured from physical assets towards BIM-based integration for asset owners to derive value from BIM investments. A qualitative case study strategy is used to study the strategic implementation process of integrating BIM with AM systems by a large asset owner in the United Kingdom (UK). Semi-structured interviews and archival analysis are used to collect data. Furthermore, thematic and document analysis are used during data analysis. This chapter identifies key strategies in the adoption of BIM-based processes, the implementation process, the challenges, and the business value attained. The study identified several challenges of adopting BIM-based processes in AM: (a) Complexity and cost associated with BIM; (b) Irrelevance of 3D-geometric data in AM processes; (c) Nature of asset ownership structure; (d) Managing the asset handover process; (e) Managing change within the organisation. Organisations will have to consider the following issues in streaming AM systems with BIM: (a) The development for a clear strategy prior to adoption; (b) Connecting the strategy to the business goals; (c) The discovery of organisational information needs in relation to business processes. Finally, the findings in this chapter underscore the significance of incorporating elements in the BIMAsset VRM that cover: (i) the development of organisational information requirements for BIM-based processes; (ii) the development of an organisational strategy for BIM-based processes; (iii) the adoption of suitable BIM standards and policies; and (iv) the development of an effective systems architecture for BIM-based processes.

CHAPTER 6

BIM BUSINESS VALUE OF AN ASSET INFORMATION MANAGEMENT SYSTEM

UNIVERSITY OF LIVERPOOL

6.0 BIM BUSINESS VALUE OF AN ASSET INFORMATION MANAGEMENT SYSTEM

6.1 CHAPTER INTRODUCTION

This chapter describes the study in relation to Research Objective 4: To investigate how the information content collected from built assets generate business value in a BIM-based Asset Information Management (AInfM) system including key techniques of managing asset data and how that data is reported for critical decision-making. This chapter seeks to address one of the research gaps identified in Chapter 2. That is, the lack of understanding of tools and techniques for effectively managing built asset data. The research problem is socio-technical in nature, that is this is social (organisational or management) and technical (BIM-AM systems). As such, the study seeks to cover social aspects of AM and AInfM strategy. The technological aspects relate to BIM-AM systems, data formats, sources and analysis. Asset owners are unaware of the management and operational benefits of BIM-based AM in the operations and use phase. This may be due to the inability of asset managers to filter valuable information from the pool of built asset data for strategic reporting and timely decision-making across their portfolio. That is, the inability to develop organisational management and operational systems to coordinate AInfM activities; and to set-up the technological systems efficiently to create, collect, store, analyse and report asset data. A single case study is adopted to achieve the research objective of identifying effective techniques for managing built asset data in order to derive BIM business value for the asset owner. The rationale here is that in order to realise BIM business value during asset operations, the asset owner needs to understand techniques to understand the business value of managing the information content that BIM enables. Therefore, there is a need to investigate aspects such as organisational strategy, information content creation, management, sharing, storage and reporting for critical decision making as factors that would influence the achievement of BIM business value through efficient AInfM by an asset owner. The importance of this chapter with respect to the development of the BIMAsset VRM is that it provides a better understanding of the justification that was made by the researcher for each of the identified elements and sub-elements. These findings are discussed and theoretically validated in Chapter 9.

6.2 RESEARCH JUSTIFICATION

The effective and efficient management of built assets alongside other physical assets such as plant and equipment can be an arduous and complicated undertaking for many asset owners. Efficient and effective AM refers to having the processes that support the appropriate management of resources including having a coordinated set of activities to organise, manage and control built assets in order to realise lifecycle value and the delivery of business objectives. More importantly, the output optimisation of these assets become critical to an organisation's business objectives. Asset owners are continuously seeking opportunities to reduce operational costs and maximise profits. This consideration makes it essential for asset managers to collect and manage the facility's asset data throughout its lifecycle. The documented asset data constitutes the information asset, which in turn enhances the ability of managers to make key decisions on their built assets in order to run them effectively and efficiently (Engelsman, 2007). However, not much research has been carried out regarding BIM business value in AM (Love *et al.*, 2013; Love *et al.*, 2014). Studies related to BIM in aspects of AM such as AInfM have not been forthcoming. There has been more research emphasis towards optimising asset performance and enhancing decision-making whilst neglecting aspects of AInfM strategies (Ouertani, Parlikad and Mcfarlane, 2008). For most asset managers, the problem is not the lack of information about their assets, but the abundance of it (Lin *et al.*, 2007; Brous, Herder and Janssen, 2016). As such, there is an abundance of unusable information and the lack of usable information. Therefore, developing a strategy to control and manage information resources is critical for asset managers to be able to harness the potential of realising BIM business value from their organisational information assets.

Information is a valuable component in the business processes of an organisation, but only a few have acquired business value from their information assets (Engelsman, 2007). The ability to identify the business value of information assets within an organisation would help the understanding of asset managers in making a distinction between more valuable and less valuable information. This could also serve as justification for IS investments such as BIM (Engelsman, 2007). The increased adoption of BIM, CAFM, CMMS, IWMS and CDEs alongside other Automated Identification and Data Capture (AIDC) technologies in AM has brought about an evolution in the way asset managers view, operate and manage their assets. These tools have the efficacy to produce operational asset data that can be used to monitor, manage and optimise asset performance. In spite of all these tools, asset managers still lack the know-how in deriving business value from the large sets of organisational information resources. Therefore, further research is needed in this area to develop models, tools and techniques to comprehensively evaluate the business value of information assets, IS, AInfM and BIM in AM (Ouertani, Parlikad and Mcfarlane, 2008; Love *et al.*, 2014; Love, Mathews and Lockley, 2015).

The purpose of this study is to investigate how the information content collected from built assets generate business value in a BIM-based AInfM system. The study aims to identify the key techniques of managing asset data and how that data is reported for critical decision-making. This study aims to clarify issues related to operational data requirements that will guide asset managers in sorting and prioritising valuable information from the pool of organisational data for strategic reporting and critical decision-making across their asset portfolio. The study investigates the process of collecting data from AInfM and BIM systems at the operational level, how the data is managed, how it is reported at the tactical management and strategic level, and the business value that can be derived from the whole process.

6.3 CHAPTER 6 – DETAILED METHODOLOGICAL APPROACH

This study aims to investigate the information asset content that drives business value in AM and how it relates to BIM. It also seeks to evaluate how asset information is collected, organised, stored, controlled, analysed, secured, shared and reported within a virtual AInfM system for strategic management-based decisions. The study will address the following research questions:

- How does the information content captured from physical assets generate business value in AM, and which aspects relate to BIM?
- What are the types of BIM business value that the captured information content may deliver for built assets?

6.3.1 RESEARCH METHODS

This research is based on a case study research conducted in a large building services design and consulting company in Finland to investigate the information asset content that drives business value in AM. Company A is a design, consultancy and software company that provides services to over 1,000 clients and asset owners in about 30 countries. This research focused on the activities of four departments at Company A. These are Manager Division, Building Automation, Digital Property Services, and Innovation and Development. These departments are responsible for handling client asset portfolios, data analytics and reporting for strategic decision-making.

Purposeful sampling is utilised for the case and participant selection. A classification of purposive sampling, namely operational construct sampling, is used based on the theoretical constructs of the study that focuses on investigating BIM business value in AM through a real-life design. The criteria for selecting this case study are: (i) they are experienced users of BIM; (ii) they utilise BIM in asset operations; (iii) they are exhibiting appropriate characteristics of BIM business value realisation; and (iv) they have established AInfM management processes for managing asset data. Furthermore, the following criteria were considered in participant selection for the study:

- Participants were senior personnel of the four departments investigated.
- Participants were both senior and junior personnel who interfaced with clients.
- Participants were senior personnel in asset monitoring and optimisation operations.
- Participants were senior personnel in the technology and innovation department who were responsible for innovation and future developments.
- Participants had advanced levels of knowledge and understanding of BIM in asset operation and management.

The above criteria are designed to ensure that the selected participants cover all departments responsible for interfacing with client requirements, asset data management and reporting within the organisation. The participants experience and knowledge of BIM were assessed during the preliminary interviews and discussions prior to the interviews. Furthermore, checking for validity is done through participant validation. The study outcome is communicated to the participants for assent (Saunders, Lewis and Thornhill, 2016). As such, the interview transcripts and analysed results were adjusted in line with the comments of the participants in order for the study to accurately represent their views and responses based on the interview questions asked.

The literature review helped to identify the domains of BIM and AInfM (Sections 2.5, 2.6, and 6.2). This activity recognised strategies of AInfM implementation by asset owners together with information management strategies and frameworks. Furthermore, the literature review critically analysed the elusive value of information and the different views and understanding of BIM. On the other hand, the case study research investigates and documents the processes of capturing and analysing asset data for strategic reporting. This stage involved two main activities; interviews and document analysis. The semi-structured interview technique is utilised to collect data. The interview questions are developed from a systematic method of thematic analysis (Boyatzis, 1998). The questions were based on a list of themes that varied from interview to interview because of the varying nature of the respondents' work (Saunders, Lewis and Thornhill, 2016). Interviews helped to collect detailed information on the processes relating to collecting and reporting asset data to clients for decision-making. Secondly, document analysis is conducted to review the content of information, data formats, data sources, operational workflows and business value derived from using AInfM and BIM systems in Company A.

6.3.1.1 RESEARCH PROCESS: DEDUCTIVE REASONING SRQ-3

This section presents the methodological process of this part of the study. Here, deductive reasoning is adopted in SRQ-3 to understand data collection, formatting, analysis, management and reporting techniques that enable BIM business value in a BIM-based AInfM system. This aspect of abductive inference of the PRQ deals with the identification of six types of values that can be derived from effective BIM-based AInfM, including key strategies for efficient AInfM. The research process is shown in Figure 6.1:

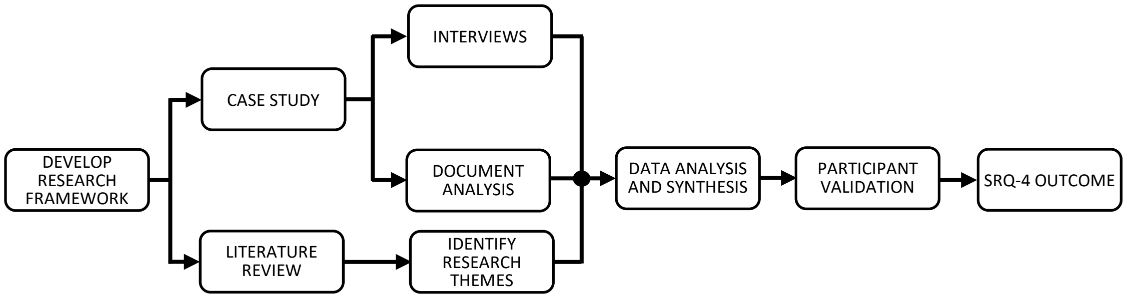


Figure 6.1: Deductive reasoning SRQ-3

6.3.1.2 DATA COLLECTION AND ANALYSIS

The study adopts a qualitative approach towards the data collection and analysis. This study utilises interviews and document analysis in the primary data collection. Seven sets of interviews were conducted and nine respondents were interviewed from different departments in Company A. Three respondents from Manager Division, two respondents from Building Automation, two respondents from Digital Property Services, two respondents from Innovation and Development. This sampling ensured that at least one person was interviewed from the operational, management and strategic reporting of asset information in Company A. After the interviews, NVivo™ software is utilised for the transcription, coding and data analysis (Bazeley and Jackson, 2013; Saunders, Lewis and Thornhill, 2016). Thematic analysis is conducted during the literature review to establish themes. This is a technique of classifying and reporting topical issues within data (Boyatzis, 1998). The process started with identifying specific issues from literature, which were arranged into themes. The themes further guided the development of interview questions for the study. The collected data is then coded into main and sub-codes and given descriptions. Coding is a technique of cataloguing data for analysis (Boyatzis, 1998). The higher-order thematic categories are used in the study to classify one or more codes in the data analysis, discussion and data presentation. The analysed data is reported in categories and notations. Table 7.1 shows the summary of the thematic analysis:

Table 6.1: Shows data themes, codes, categories and notations

S/N	THEME	CODE	CATEGORY	NOTATION
1	Organisational Asset Information Management Strategy	AInfM Strategy	Section 7.4.2	Company A's AInfM Strategy
		BIM Strategy	Section 7.4.3	Company A's BIM Strategy
2	Asset Information Management	Data Formats	Section 7.4.5.1	Asset Data Collection, Formats and Sources
		Data Requirements	Section 7.4.4	Asset Information Requirements
		Data Sources	Section 7.4.5.1	Asset Data Collection, Formats and Sources
		Data Analysis	Section 7.4.5.3	Asset Data Analysis
		Data Reporting	Section 7.4.5.4	Asset Data Reporting
		Data Sharing and Storage	Section 7.4.5.2	Asset Data Transfer, Handling and Storage
3	Business Value	Information Value	Section 7.4.6	BIM Business Value
		Client Value	Section 7.4.6	BIM Business Value
		BIM Business Value	Section 7.4.6	BIM Business Value
		Challenges	Section 7.4.7	Challenges of the System

The thematic analysis process started from the literature review exercise, where three themes were developed: Organisational Asset Information Management Strategy, Asset Information Management and Business Value. Additionally, these thematic classifications guided the development of interview questions for the study. The thematic categories shaped the topical issues of which the interview questions were predicated upon. Furthermore, the thematic categories guided the development of codes during the analysis of qualitative semi-structured interviews. Thus, similar codes were grouped together into categories and given labels or notations in the presentation of results in the following sections.

6.4 RESULTS: CASE STUDY: BIM-AInfM SYSTEMS AT COMPANY A

The results presented in this section and sub-sections are from the findings of the semi-structured interviews and archival analysis.

6.4.1 INTRODUCTION OF THE CASE

Company A is a design, consultancy and software company in Finland. This company has been implementing BIM solutions for clients globally. They offer a wide range of AInfM solutions with analytics that provide tools for asset managers to plan and execute tasks such as maintenance management, energy monitoring and reporting, contracts management, long-term planning of repairs and refurbishment. These tools assist asset managers in understanding their buildings better and facilitating informed decisions on strategic and planned asset interventions. The utilisation of the BIM tools together with AIDC technologies and the Internet of Things (IoT) integration empowers asset managers with an ability to monitor and evaluate their assets in almost real-time. This includes monitoring meter readings of energy consumption, monitoring heating and cooling, managing service requests and associated time schedules. Furthermore, Company A has identified areas where BIM can be of value to their clients' business operations, such as maintenance, service requests, facility access, classification of spaces, workplaces, contract areas, indoor air quality and design target of spaces.

6.4.2 COMPANY A'S AInfM STRATEGY

Company A has developed an AInfM strategy for managing its asset data. This is divided into three sections of organisational management, namely; operational, tactical and strategic levels (Figure 6.2). Similarly, these classifications have been identified by Marquez (2007) and Chemweno, Pintelon and Horenbeek (2015), who examined the same three classifications of operational maintenance activity levels in AM.

- **Operational level:** Activities at this level would ensure that asset maintenance tasks are executed by a skilled technician as scheduled in the maintenance plan, which would be input into the information system (Marquez, 2007). In order to execute the maintenance tasks, activities for preventive maintenance, reactive interventions, troubleshooting and diagnosis will be carried out on the assets. Therefore, the collective set of actions at this level spell out the operational level functions. At this level, asset data is collected in Company A through data sources that come from static and dynamic datasets. Asset data is recorded according to individual tasks, contracts, with or without a link to other assets.

- **Tactical level:** Actions at the tactical level aim to ensure the appropriate allocation of maintenance resources in order to effectively execute the organisational maintenance plan (Marquez, 2007). In order to execute the maintenance plan, an organisation will have to appraise different alternative resource options, including detailed maintenance requirements, planning and scheduling models. Therefore, these sets of actions would detail the tactical maintenance policies of an organisation. At this level, Company A collects data and provides a platform for viewing and appraising assets in a group. This could be as a group of similar types of assets or a group of assets in a space or floor.
- **Strategic level:** Activities at the strategic level aim to convert business priorities into organisational maintenance priorities by establishing critical targets in current operations (Marquez, 2007). In order to achieve these targets, the organisation will develop mid-to-long-term strategies to address current lapses in asset maintenance performance. Therefore, a generic maintenance plan in relation to organisational business objectives will be developed at the strategic level. At this level, the asset portfolio data in Company A is presented in summaries and visual formats for managers at the strategic level to have an overview of the overall performance of the entire portfolio including data from individual assets. Also, Company A has a unique way of utilising the traffic light colours to indicate performance for easy comprehension.

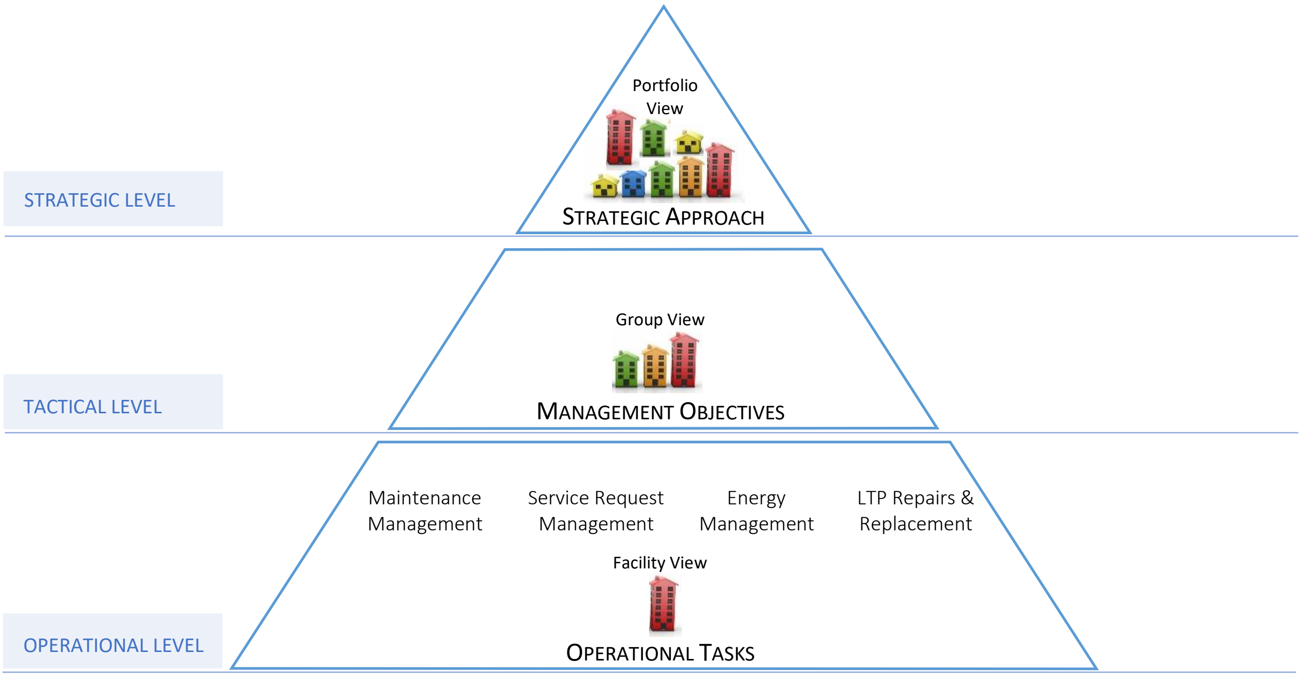


Figure 6.2: Company A's asset management levels adapted from Hänninen (2011)

Furthermore, Company A advocates for its clients to adopt both top-down and bottom-up approaches in implementing their AInfM system.

6.4.3 COMPANY A'S BIM STRATEGY

Company A's BIM strategy aims to provide a platform for the development of information assets where the facility and end-user will communicate by connecting through silos of information within a client organisation. Information assets are defined as data that is or should be documented that has value or potential value. Company A aims to actualise the immediate and growing expectations of BIM for their clients. As such, they have developed a strategy to enable the development of platforms and capabilities to realise their vision of where the facility and user will communicate. That is to focus on the development of BIM capability as a: (i) communication tool; (ii) visualisation platform; (iii) building performance optimisation tool; (iv) platform for information creation; (v) data management platform; (vi) user-centric approach for value delivery; and (vii) facility digitalisation. The components that enable the BIM strategy are presented in seven aspects shown in Figure 6.3:

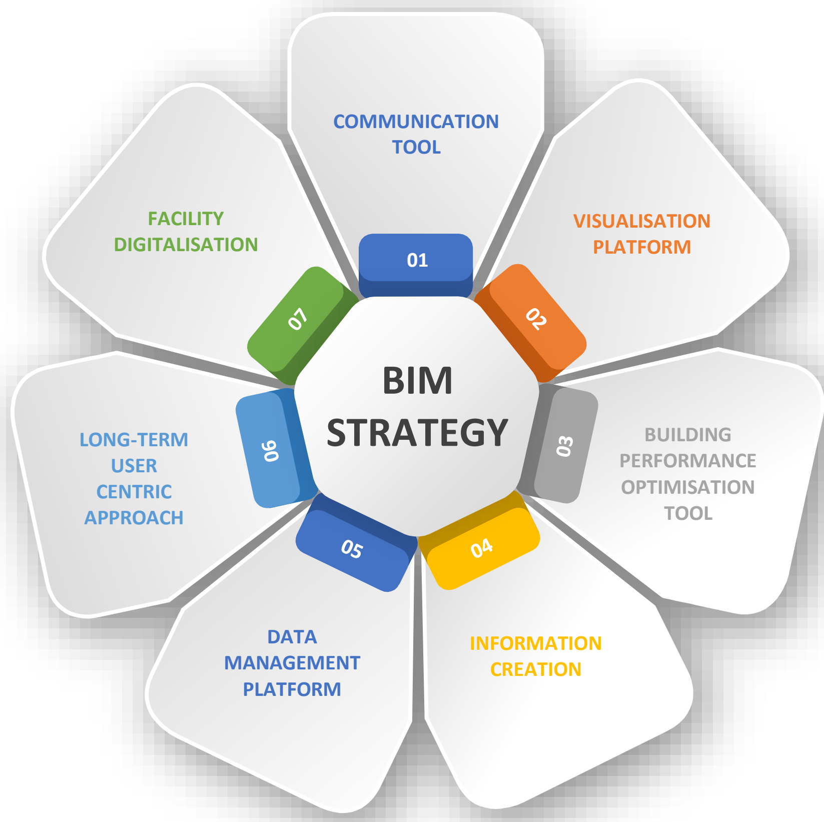


Figure 6.3: Company A's BIM strategy

Furthermore, Company A has developed a roadmap for its innovation plan to articulate how it forecasts the development of BIM systems and the responsiveness of the facility as technology continues to develop. The first is the basic functionality where the BIM systems act as a platform for visualisation. At this stage, it becomes a connection node between the Building Management Systems (BMS) and users to evaluate the performance of a facility. The next phase denotes its evolution into a data analysis and optimisation platform, which would enable asset managers to utilise IoT data generated by the facility. The amount of asset data generated by built assets is expected to increase exponentially, therefore, a platform with different user interfaces for aggregating that data will be necessary. The next level is where a reporting facility emerges through the big data. Large sets of information will be available for the asset owner, which would enable the facility to achieve this level of maturity. The next phase is the predictable facility where algorithms are developed to predict asset performance or failure. This would change the model of asset intervention from a need-based to a demand-based approach. Subsequently, a learning facility emerges through the harnessing of predictive data and the further development of algorithms. The final stage would involve the development of a thinking facility, with a facility that could reason through the large datasets in order to be able to optimise asset performances. The stages are shown in Figure 6.4:

Figure 6.4: Company A's innovation roadmap

6.4.4 ASSET INFORMATION REQUIREMENTS

Company A has a formal process for documenting and analysing asset information. This template contains KPIs, which guide the data collection processes. Furthermore, specific requirements on building details, energy data, contract details, planning details and performance optimisation are collected from individual assets. Figure 6.5 contains the parameters and priorities of the asset information requirements for the Company A AInfM system.

BUILDING DETAILS

- Area/volume
- Building usage type
- Year of built/renovation
- Number of people
- Address
- Owner
- Type of HVAC system
- Year when airflows were calibrated

ENERGY DATA

- Energy consumption heating
- Energy consumption electricity
- Energy consumption cooling
- Water consumption

CONTRACT MANAGEMENT

- Cost per year

LONG TERM PLANNING

- Planned maintenance costs all types
- Planned maintenance costs all types - subtasks

PERFORMANCE OPTIMISATION (MATRIX SCORE FOR EACH PERFORMANCE KPI

- Average of the 3 categories written below:
  - System energy performance
  - Indoor conditions
  - Operability
  - Cost per year

Figure 6.5: Parameters and priorities for asset information requirements

6.4.5 IMPLEMENTATION/REPORTING PROCESS

At the beginning of the implementation process, Company A developed a four-level reporting process for its AInfM strategy. They are asset data collection, formats and sources; asset data transfer, handling and storage; asset data analysis; and asset data reporting. This is shown in Figure 6.6:

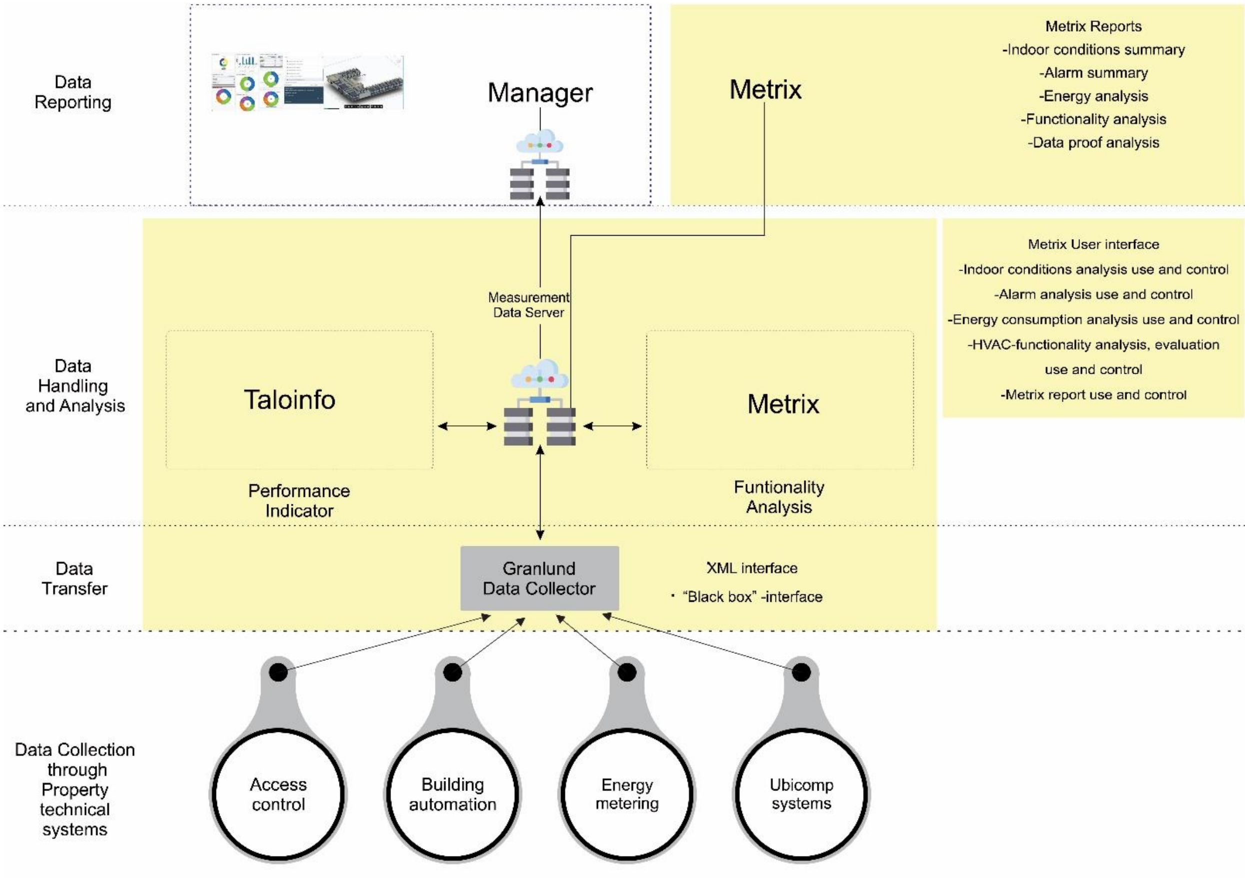


Figure 6.6: Company A's AInfM reporting process adapted from Hänninen (2011)

6.4.5.1 ASSET DATA COLLECTION, FORMATS AND SOURCES

This level is at which asset data is collected through sensors and manual input from every work-station that is responsible for asset maintenance. Data collection is done according to individual tasks assigned. A variety of data formats are utilised during the AInfM data collection process. These depend on graphical and non-graphical data that is captured. The data supported formats by the AInfM and BIM systems are presented in Appendix F.

Asset data is sourced in Company A from two main points of supply, these are, static and dynamic. Static asset data is usually documented information that is from Industry Foundation Classes (IFC) models and maintenance manuals. Dynamic information is data from IoT sensors, building automation data and feedback from end-users. A combination of both static and dynamic information forms the main source of data for the digital twin. A digital twin is a digital replica of a physical asset, component, product or system including its physical, functional and operational data in all the lifecycle phases (Schleich *et al.*, 2017). The data sources are shown in Figure 6.7:

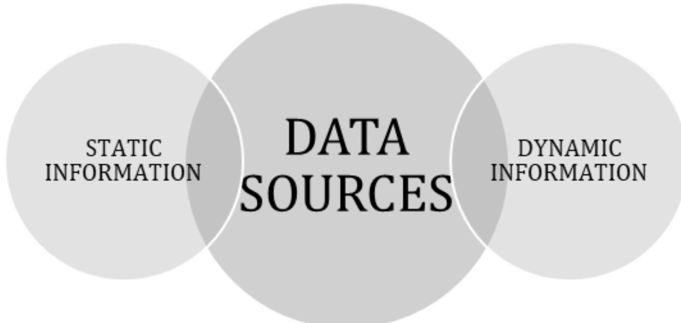


Figure 6.7: Company A's data sources

The asset database structure for dynamic data generated from built assets has two source points; Alarm Point and Measure Point. These are shown in Figure 6.8:

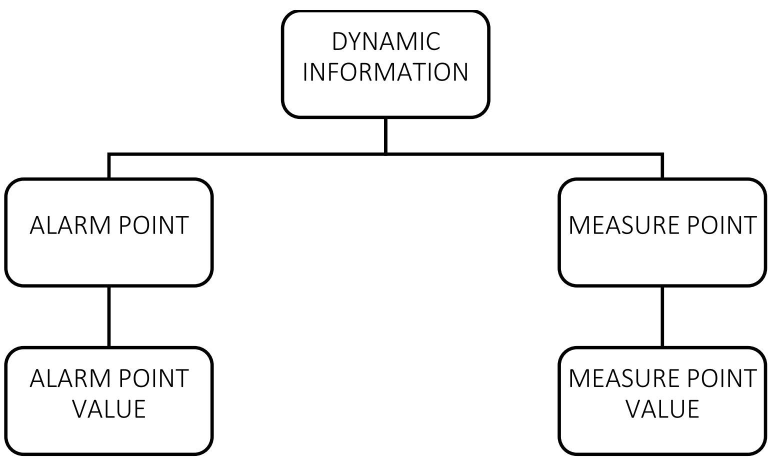


Figure 6.8: Company A's asset database structure for dynamic information

6.4.5.2 ASSET DATA TRANSFER, HANDLING AND ANALYSIS

Data is transferred across the AInfM and BIM modules in approved formats and stored in a database that is linked to the Company A Manager module. The approved formats are shown in Appendix F. Data handling is done using a user interface where the data is visualised. Data are collected by setting a software layer over the BMS in each building, and the data is sent in batches to the Cloud service or analytics.

Data analytics are achieved through the Company A Metrix module, which calculates ratios, performance indexes, and deviations, and other forms of analysis. The maintenance system allows for different kinds of analysis. The highest level is the real estate or building group. This group is further sub-divided into various composite buildings. The buildings are further divided into floors and spaces. Finally, it is classified into technical areas such as construction, HVAC and energy consumption. The level of analysis is shown in Figure 6.9:

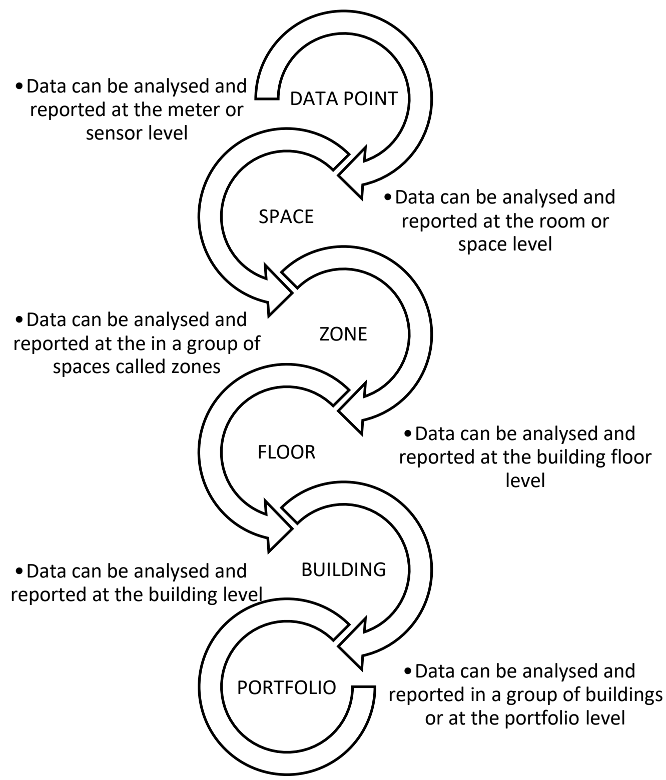


Figure 6.9: Levels of data analysis

The details for the analysis to be conducted are usually defined by the client according to their business needs. The level of analyses is referred to as KPIs in systems utilised by Company A. There are three major classifications of analysis carried out by the AInfM system at Company A, they are; Energy Performance, Operability and Long-term Planning. Another aspect of analysis that can be conducted is to measure utilisation. This can be done through a combination of other functionalities such as lighting presence detectors, desk occupancy sensors and meeting room booking platforms.

Company A has a team of experts who can follow-up on asset data. These experts can read the data and use analytics to identify any peculiarity. The performance optimisation module gives impulses on which systems are being operated the way they should and which are not. That way, the systems can be optimised. Once the problem or deviation is noticed in the data, the analytics team creates a service request or develops a report where the client is notified of the faults and should attend to it. Furthermore, there is the option of remote connection to the systems, where the analytics team can actually control the building and make changes to the setpoints or time schedules. This is similar to the data results from the BMS, where all the alarm data from the system is collected. The course of action will depend on the terms of engagement and organisational setup of the client or asset owner.

Company A has adopted the approach of using IFC when reviewing static data for analytics. This is because IFC is a snapshot of some static information contained in the digital representation of the facility. Connecting to native building information models may not be the appropriate way to approach base data for analysis because it may change constantly depending on how frequent it is updated. This data is visualised through the Digital-Twin module. The Company A Metrix module can perform analytics at the building level, floor level, room level or desk level. This, if the systems are able to report at an accurate level, then there is more value for the asset owner in terms of the levels of analysis that can be conducted.

6.4.5.3 ASSET DATA REPORTING

The report assembler of the Company A Manager module produces the summaries of all appraised assets within the building or portfolio. These reports are generated from the outcome of the analytics department and then reported to the asset managers. As a follow-up, Company A provides support services to the local service organisation to improve the performance of the facility. The types of asset data reported are focused on four key KPI categories: System Energy

Performance, Indoor Conditions and Operability. The units of data reported are (but not limited to): area, volume, building usage type, planned maintenance costs, energy consumption (heating, electricity, cooling), water consumption, outdoor temperature, pressure measurements and heat recovery. Furthermore, the properties of the data consist of the following (but not limited to): time, date, priority, point ID, alarm description and alarm state. The asset data from the facility is generated hourly and analysed daily. There are 24 measured values that are received once per day from the building automation system. Normally, the data gets analysed and reported a day later. The respondents assert that this time limitation comes from the building automation systems. On the other hand, asset data sourced from the Cloud can be reported more in real-time at the sensor level. This is shown in Figure 6.10. The formal typical reporting cycle for the portfolio is monthly or quarterly, depending on the service-level agreements with clients.

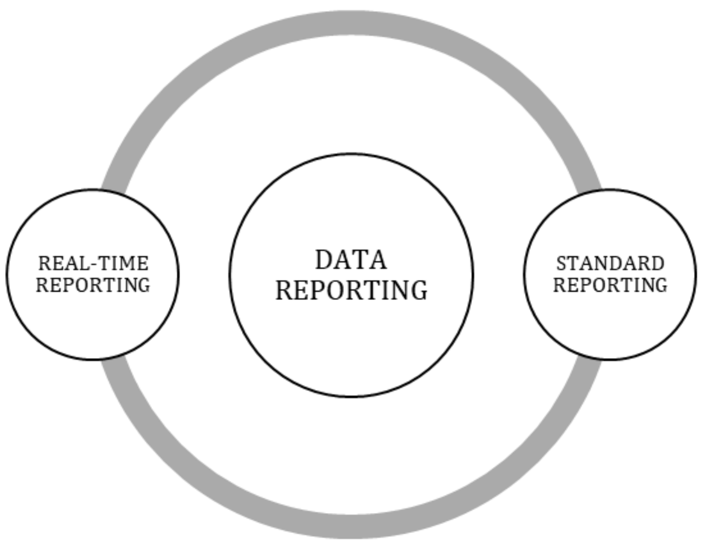


Figure 6.10: Data reporting types

The asset or building data can be summarised and reported at the portfolio, building, floor, room, or asset level. Asset data can be reported at any level the asset owner wishes to view the data. There are many ways to view the data, and this will depend on the type of analysis requested by the asset owner. On the virtual dashboard of the Manager module, the asset manager can view the building performance. There is an index for energy efficiency, functionality and indoor environment. The index is a score that measures building performance. These indexed processes are also allocated with colours similar to the traffic lights for easy visualisation. This is to assist the asset manager to easily understand whether the asset portfolio is being run as it should. All these processes have sub-processes with sub-indexes right through to the sensor level. There are usually service level agreement meetings quarterly. In terms of support, staff from the analytics team are in contact on a weekly or monthly basis, and if there is something urgent, then it is done on a daily basis.

6.4.6 BIM BUSINESS VALUE

The study identifies six aspects of BIM business value that may be of benefit to the asset owners' business objectives and environment, which are: management, commerce, efficiency, industry, user and technology value (Figure 6.11). Chapter 7 addresses the techniques of appraising BIM business value presented in this section.

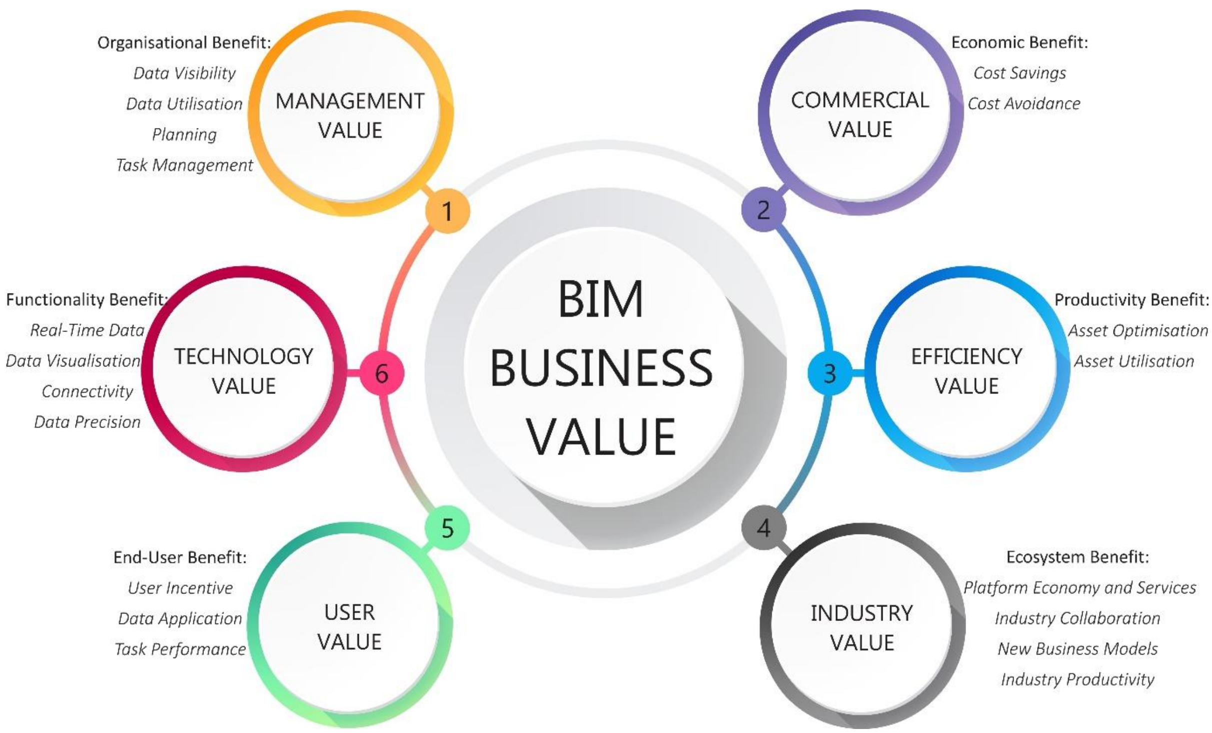


Figure 6.11: BIM Business Value in AM

6.4.6.1 MANAGEMENT VALUE

From the management perspective, BIM delivers value for the asset owner at the strategic, tactical and operational levels. BIM utilisation in AM has the potential to stimulate innovation and support a collaborative culture for the asset owner. The business value identified here are; the effective use of data; the better planning of spaces; improved asset data visibility and task management; and an enhanced maintenance culture. The management value identified here is mostly intangible (Carayannis, 2004; Nogeste and Walker, 2005).

At the strategic, tactical and operational levels, BIM can influence the effective use of data within the organisation. The use of BIM systems helps the asset manager to better utilise data by effectively monitoring key assets. The KPIs reported throughout the systems are adapted to the asset owners' management strategy. These KPIs are aimed at monitoring strategic, tactical and operational management objectives. Similarly, the systems help bring out deviations in asset data, and this, in turn, enhances the proficiency of the asset manager to properly investigate problems in order to find a fix. This capability will help asset managers plan asset maintenance in an efficient, effective and strategic manner.

Furthermore, at the strategic and tactical levels, BIM systems can enhance general planning and improve an organisational set-up. Asset managers can plan operations and allocate spaces better with the provision of accurate asset data from the BIM systems. Space allocations and travel path analysis can be conducted using the BIM systems together with BMS and IoT data. For example, an asset owner may require additional two-person meeting rooms for a particular purpose, and there exists a five or ten-person meeting room that is not utilised. Data from the systems can be used to identify the least utilised room so that it can be re-assigned. Another example is of an office building that is not fully utilised at a specific time of the day, and at that specific time, there are personnel working randomly in different sections of the building. Here, the asset manager could reflect on the data in order to plan the workspace to be more efficient and save costs. These are all aspects of business value that BIM could bring to the asset owner by enhancing AM efficiency, cost benefits, waste reduction and business opportunities.

Management value is derived at the strategic, tactical and operational levels through improved visibility of asset data and enhanced task management. Using the BIM systems, the asset manager can gain a deeper insight into detailed asset data including service areas, asset locations and maintenance history. This data can help the asset manager in developing an effective asset maintenance plan. Also, the system colour codes are visual aids that help the asset manager to comprehend summary reports at the strategic level instantly. The green, yellow, red and blue lights indicate complete, in progress, overdue and scheduled tasks respectively. Asset managers are able to track new service requests, open requests, task considerations, and the number of completed tasks over a particular period. Also, the asset manager can utilise the BIM systems to monitor service provider portfolios. The systems can track supplier data such as trends and performance, which will guide the asset manager in executing the overall building maintenance management plan.

At the operational level, the BIM systems can improve the culture of planned preventive maintenance by facilitating asset maintenance through data. The asset manager is able to utilise data from the systems by comparing the performance of similar assets in order to identify the most efficient maintenance routines for the facility. For example, there could be two air handling units in the same building; one running for 300 hours per month and the other running for 700 hours per month. Typically, both are serviced with the same frequency and at equal intervals in a year. Having access to this type of data will assist the asset manager to identify which asset is under-maintained, thereby, enhancing the maintenance culture of the organisation.

6.4.6.2 COMMERCE VALUE

BIM can deliver commercial value for the asset owner through improved financial performance and profitability. BIM utilisation would impact maintenance costs, replacement costs, energy costs and occupancy costs through cost savings and cost avoidance. The value realised here are both tangible and intangible (Carayannis, 2004; Nogeste and Walker, 2005).

Commercially, the benefit to asset owners is in two parts; cost savings and cost avoidance. Cost saving is referred to any action that results in a tangible benefit that lowers current spending, investment, or debt levels for an organisation, whilst cost avoidance is defined as is any action that avoids incurring of costs in the future. As such, cost savings are hard (tangible) savings, while cost avoidances are soft (intangible) savings. The BIM systems can bring about cost savings during asset operations. The utilisation of BIM can enhance the running and maintenance of assets, as a result, contributing financial benefits to the asset owner. Cost savings are achieved through effective monitoring of assets with the BIM systems to detect deviations in performance. From the semi-structured interviews, one respondent indicated that the data analytics module (Metrix module) detected some air handling units that were running for 24-hours instead of the initial 17-hour daily programming. The problems were corrected, and savings were realised from the solution. Instances like these bring direct cost savings to the business. Other aspects of BIM business value that bring about cost savings include: effective space planning, check to the operational asset hours, and the planning of maintenance schedules. When spaces are better planned, there would be a reduction in energy costs and enhanced space efficiency. When assets are monitored effectively, there would be a reduction in the down-time hours. When maintenance schedules are designed with reliable and accurate data, assets would have longer lifecycles. The enhancement of all of these activities by the BIM systems can generate revenue for the business and enable the asset manager to get more use out of the asset.

Cost avoidance, on the other hand, is a significant benefit that BIM brings. Cost avoidance involves any added functionality or pre-emptive actions that result from utilising BIM systems, which enable the asset owner to avoid incurring costs. Effectively monitoring assets and correcting deviations can save costs as a result of utilising BIM systems. If the deviations are not corrected, it would cost the asset owner energy and maintenance in the long-run. Another aspect of cost avoidance is optimising the systems to operate so that there are no on-call alarms. The elimination of these alarms would typically bring about cost avoidance because the asset owner would not incur the costs of specialists to check the physical assets during on-call hours, which averages between €200 to €300. As a result, there is a commercial business value to the asset owner if the BIM systems can be optimised to operate efficiently.

6.4.6.3 EFFICIENCY VALUE

Efficiency value from the enhanced operations in AM is another aspect of BIM business value that can be derived by the asset owner. The business value identified here are asset optimisation and an improved utilisation of the building. The value realised here is mostly intangible, but there are also tangible aspects (Carayannis, 2004; Nogeste and Walker, 2005).

The BIM systems have the potential to provide reliable data to the asset manager that will support asset optimisation. The performance module gives impulses to the asset manager on those systems that are operated the way they should, and those that are not. The BIM systems act as an activity bracelet for the entire building by monitoring asset condition and performance. The asset manager is able to see the current and historical performance of all assets contained in the facility. The asset manager may utilise a remote connection to make changes, correct setpoints and/or amend system time schedules. The systems provide visibility for all data – what has been going on and how the systems have been performing – whilst giving the asset manager the opportunity to optimise the facility through data. Data evaluation using the BIM systems is more effective than traditional building audits because the asset manager is able to view system performance for wider ranges of time periods. The systems measure many asset performance parameters such as, but not limited to: outdoor and indoor temperature; indoor humidity measurements; supply air temperature including heat recovery; extract air temperature; Carbon Dioxide (CO_2) measurements; night ventilation and time lag switch status; volatile organic compound measurements; heat recovery valve position; heat recovery damper position and rotation speed of the heat recovery wheel. The time, date and unique meter identifier parameters are recorded alongside the measurements.

Another aspect where the asset owner can derive efficiency value through the data provided by the BIM systems is in measuring the utilisation of the building. A combination of more than one functional reading could be used to measure how the building is operated. For example, the first set of data from a lighting presence detector, combined with the second from a temperature sensor and the third from a meeting room booking system may give the asset manager a fourth functionality that measures utilisation. These datasets give the asset manager the opportunity to create value through making organisational operations more efficient and effective.

6.4.6.4 INDUSTRY VALUE

Another element of BIM business value is industry value. This is where value can be derived exclusively or collectively as a result of corresponding functionalities, services, and professions in the AEC industry. Some of the business value identified here are: platform economy and services; enhancing collaboration between companies; the development of new business models; and the improvement of overall industry productivity. The term industry may be broad and wide-reaching in scope and relationship structure. However, industry here refers to the AEC industry, which consists of other stakeholders that could transmit or share value with the asset owner due to collaboration supported by the BIM systems. Value realised at this level is mostly intangible (Carayannis, 2004; Nogeste and Walker, 2005).

BIM business value can be derived by the asset owner from the platform economy and services through smart cities and IoT data. As facilities become more digitised, there are many National Strategies and Policy Documents to digitalise the built environment (Kassem, Succar and Dawood, 2013). Since AM at its core aims to realise the lifecycle value from assets in the delivery of business objectives, the collaboration and added functionalities brought about new business models from the platform economy could enhance the utilisation of built assets. Asset owners with highly matured BIM programmes will be able to connect to the opportunities that platform economies provide to the AEC industry. Platform and sharing economies have the potential to reduce operational and transaction costs. Furthermore, the AEC industry could benefit from sharing and flexibility of buildings, and this would improve space utilisation in the built environment. There are long periods of inactivity within personal and public spaces in residences, offices, education, leisure and business premises in our underutilised built environment (Braiterman, 2011). More flexibility and sharing of buildings would make investments in the AEC industry more attractive because more revenue will be generated as a result of the increase in activity. Better utilisation of spaces will derive value for the asset owner together with environmental benefits in the long-run. Hence, the perspective of industry value in this case.

Another aspect of BIM business value is enhancing collaboration between stakeholder organisations. The BIM systems provide an opportunity for collaboration with other stakeholders with the aim of enhancing the value stream by adding more functionalities to the BIM systems in collecting, analysing and reporting asset data. The first part is achieved by automating the maintenance process, starting from the dispatch of work-orders, through to the tender process, including invoicing and sign-offs. The BIM systems can facilitate the development of a collaborative culture for all stakeholders with benefits of less cost and higher quality for the asset owner. This in turn, improves productivity by eliminating the traditional adversarial relationships of the AEC industry (Latham, 1994; Egan, 2008). Furthermore, the systems also provide the opportunity of collaborating with technical partners and start-ups in asset optimisation. The asset manager can source for open Application Program Interface (API) for certain devices from the manufacturers in order to access the signals to monitor performance and to optimise the facility.

The utilisation of BIM systems could derive business value through the development of new business models in the AEC industry. The systems will act as an interaction node for navigating the large sets of asset data between industry actors and building or city digital twins. The increase in quality data from these systems could help to develop new business models that will be focused towards a better utilised built environment. For example, better detailed asset information on air handling units, floor-level submetering, floor-level CO_2 and the like will facilitate new business models that will explore asset data with reference to the facility geometry, albeit, for the benefit of the asset owner. Similarly, the provision of other services could serve as enablers for external business models such as smart grid solutions, real-time data and maintenance on-demand. These businesses will connect to the facility, and the asset owner will benefit from all the services and data that would be provided by these business models. The new business models could add functionalities such as pre-testing, pre-fabrication, self-diagnostics and machine learning that will improve the overall service delivery of the industry.

Improvement of overall industry productivity is another BIM business value that could be derived from increased BIM adoption. There is huge potential to improve building performance using BIM systems because the operations sector is plagued with poor performance, lack of productivity and lack of innovation. These systems support businesses and start-ups in the building services sector to utilise asset data and analytics to optimise building performance. There are business models within the supply chain that provide analytics and other support services to asset owners to improve the performance of the building. Furthermore, increased collaboration mentioned above makes this process evermore easier to execute, thereby creating value for all stakeholders.

6.4.6.5 USER VALUE

BIM can drive business value for individual actors that use the systems in performing daily tasks. The utilisation of these systems can add value to overall organisational performance and productivity. The BIM business value identified here are: user incentive; multiple user data perspectives; and higher employee productivity. Value realised at this level is mostly intangible (Carayannis, 2004; Nogeste and Walker, 2005).

The BIM systems provide an incentive for users because they save time, simplify tasks and provide accurate data. The systems report KPI data that are specific to users and their daily tasks. The asset owners' internal business needs for reporting comes first. This user-centric view creates dependability on the systems by reporting KPIs that focus on organisational business activities. Another BIM business value is multiple perspectives of the same asset data. The data reported by the systems can be viewed and utilised by different professionals within the same organisation. For example, an analysis conducted by Company A aimed at analysing the utilisation of a facility by using lighting sensors in a building had the following outcomes; the team manager focused on appraising productivity and punctuality; the energy manager focused on energy efficiency; and the space manager focused on space efficiency and analysing the options in relation to room and space allocations. The dataset had enough information for all these professionals to make reasoned judgements. With a user perspective, there are many benefits that can be gained from the large sets of asset data generated by the BIM systems, which would be relevant to many aspects of the asset owners' business processes.

Another aspect of BIM business value is enhanced employee productivity as a result of accurate data, improved data delivery and task automation. The BIM systems have the potential to filter and sort data automatically for user task execution. The system allows users to navigate through the large inventory of data to be able to answer simple queries with which to perform their daily tasks. The ability of the systems to provide the right information at the right time for the right user to perform a task creates value for the end-user.

6.4.6.6 TECHNOLOGY VALUE

Technology value is an element of BIM business value that the asset owner can benefit from. The types of business value identified here are: real-time data from 3D building information models; the visualisation of asset data; data connectivity; and precise level of reporting. Value realised at this level is mostly intangible (Carayannis, 2004; Nogeste and Walker, 2005).

The BIM systems have the technical capability to provide real-time asset data of the building. Therefore, it will be crucial for the asset manager to be able to know the asset readings immediately. For example, if the temperature is too high or too low, the asset manager should know immediately and not when the reports come in a day, week or month later. The dynamic real-time IoT data can be integrated to the IFC models or the facility digital twin. The asset manager can access real-time data on space and desk usage, noisy zones, heat maps and other KPIs or asset parameters. The retrieval of real-time asset data will be useful in optimising the building, and this capability will drive business value for the asset owner.

Another benefit that technology brings is data visualisation. The presentation of asset data for easy comprehension and utilisation is of great benefit to the asset manager. The BIM systems provide an interface for visualising asset data either in dropdown lists or in 3D-view. This visual interface is crucial because it would be impossible for the asset manager to filter and utilise all asset data coming from the BMS and IoT using traditional methods such as spreadsheets. Also, the presentation of data using colour codes and programmed filters by the BIM systems makes it easy to comprehend, and in turn, facilitate prompt decision-making.

Data connectivity is another business value that technology brings to the asset owner. The systems support the sharing of data and stimulate collaborative working by bridging data connectivity between diverse systems and by breaking down the silos of information within organisations and across the supply chain. Furthermore, data connectivity such as remote access enables the asset manager to simulate the building in the Cloud, thereby, making it easier to collect data, connect systems, analyse and optimise assets.

Another technological value of the BIM systems is the precise level of analysis and reporting. The systems have the ability to perform analysis at the portfolio, building, floor, space, zone and data point level at an accurate degree. This capability enables the asset manager to answer management queries that would be impossible to achieve using traditional methods.

6.4.7 CHALLENGES OF THE BIM SYSTEMS

The findings in this section and sub-sections emanate from the semi-structured interviews. The study has identified the following challenges of the BIM systems, they are:

- Lack of business models that support BIM utilisation
- Standardisation of information requirements
- Limitation of building automation systems
- Difficulty of getting users to engage with the BIM systems
- Difficulty of maintaining an up-to-date building information model

6.4.7.1 LACK OF BUSINESS MODELS THAT SUPPORT BIM UTILISATION

One of the problems of the AEC industry that acts as a barrier for BIM implementation is the business models that are currently operational. This is because the margins are not fairly distributed and the businesses at the bottom of the chain do not feel the need to improve. The maintenance sector is very competitive, price levels are down, personnel work under pressure, hence, the reason for the manifestation of high-level of customer complaints and low customer satisfaction in the building services business sector. Furthermore, the adversarial relationships are predominant in the AEC industry (Latham, 1994; Egan, 2008). There are no shared common goals between the investor, constructor, and end-user. The higher a business is in the value chain, the better it earns and vice-versa. As a result, businesses at the low end of the chain are restricted to the lowest-cost business models, which stifles innovation in the building services sector. This leads to the situation where very often the end-user is not satisfied. There is huge potential to improve the building performance through pre-testing, prefabrication or self-diagnostics along with other technologies, but the current business models are obstructing progress in that direction.

Secondly, as technology progresses, there would be new business models that would help drive innovation in the building services sector. This could be business models associated with smart cities, platform economies, smart-grid solutions or on-demand maintenance solutions that would utilise IoT and BMS data for revolutionised maintenance techniques. Currently, these types of business models that may stimulate BIM implementation in AM do not exist. Furthermore, when asset data is looked at in perspective, there are currently very few data points in buildings. As the market moves towards multiple data points per building the geometry relationship will be needed, and it is only if business models in relation to this come into the market that the rate of BIM implementation would increase.

6.4.7.2 STANDARDISATION OF INFORMATION REQUIREMENTS

Currently, there are no specified requirement standards on how the design process should produce the data for the maintenance phase. Another challenge is personnel in the operations and use phase cannot utilise data from building models handed over from the design and construction phases because they do not contain the information that they need. Furthermore, there is a need for a more integrated design process where personnel in the operations and use phase are engaged earlier in the process. This would make the information flow process in the design process more fluid so that requirements are captured. This assertion accords with existing literature (Becerik-Gerber *et al.*, 2012; Kiviniemi and Codinhoto, 2014).

6.4.7.3 LIMITATION OF BUILDING AUTOMATION SYSTEMS

One of the challenges of BIM implementation in relation to the management of asset data is the limitation of current building automation systems. The limitations are of different types:

1. **Types of data for analysis and reporting**: One of the challenges of utilising building automation data is the variety of datasets and formats. The system needs to have the capacity to connect to many devices and to integrate the data generated into the database. Also, there are many ways of interpreting the data. Each profession or department has its own business process with different perspectives, and they may have different interpretations of the same data.
2. **Real-time Information or data**: Another major challenge is collecting asset data in real-time. For example, if there are unusual indoor conditions in the facility, the asset manager would want to know immediately, not the day after. That challenge comes from the limitations of the building automation systems. For example, Bluetooth and radio frequency do not have the capability to report asset data every second. Also, the traditional systems that are not connected to the internet are manually reported once a day.
3. **Data accuracy:** This is another limitation of the building automation systems used to collect data. This presents an impasse for the asset owner because the very accurate sensors are expensive. Therefore, there is a trade-off between accuracy and cost. Also, there is the concern of privacy in situations where employees are made to wear electronic tags. As a result, data analytics will have to make use of non-sensitive imperfect signals such as the number of times the lighting systems are triggered or the number of times the doors are opened. The accuracy, cost and privacy factors are limitations of utilising the perfect signals that could be generated from building automation systems.

4. **System Automation:** Another limitation is system automation. Even though data can be generated automatically from the assets, a second level of automation is required, which is detecting the faults. Machine learning and prediction is a challenge for building automation systems. If the analytics team do not sift through the data or if rules are not programmed, the anomalies would not be detected by the system. Further development of the rulesets that can filter and alert on important deviations within the database is required.

The above assertions accord with existing literature (Domingues *et al.*, 2016; Aste, Manfren and Marenzi, 2017).

6.4.7.4 DIFFICULTY OF GETTING USERS TO ENGAGE WITH THE BIM SYSTEMS

Another challenge is motivating users to engage with the systems. This is because the end-users see no incentive in engaging with the BIM and AInfM systems. There is potential to collect data from users that would support the asset manager in optimising the systems. The BIM systems have to be simplified for the end-user to learn and gain some benefit. Further research is required in looking at end-user value and value streams that would help in developing systems that would provide services that the user perceives as valuable. This assertion accords with existing literature (Terreno, Anumba and Dubler, 2016).

6.4.7.5 DIFFICULTY OF MAINTAINING AN UP-TO-DATE BUILDING INFORMATION MODEL

The cost of maintaining an up-to-date building information model or digital twin is a barrier to integration. This is because it is a costly and complicated process. The integration will only happen if the business value brought by BIM are greater than the costs incurred in maintaining the system. There has to be real value before the asset owner would invest in building and maintaining the digital twin. Furthermore, the asset owners do not have the process to update the information models. This view accords with existing literature (Eastman *et al.*, 2011; Patrick, Munir and Jeffrey, 2012; Bosch, Volker and Koutamanis, 2015; Kassem *et al.*, 2015).

6.5 CONCLUSION

The purpose of this study is to evaluate how asset information is collected, organised, stored, controlled, analysed, secured, shared and reported within a virtual AInfM system for strategic management-based decisions. The study findings show that there is a lot of potential for BIM to deliver business value in AM. The study critiques the definitions of BIM and identifies AInfM strategies through literature and the lack of consensus on the evaluation of the value of information. Furthermore, the research clarifies an industry-wide misconception of BIM capability. The view that BIM capability is only effective when an organisation has the ability to collaborate with stakeholders in a work environment integrated with 3D spatial data. The study identifies the key techniques of managing asset data and how that data is reported for critical decision-making. Also, it clarifies certain aspects of data requirements that will assist asset managers in filtering valuable information from the pool of information assets for strategic reporting and timely decision-making across their portfolio.

The findings in this study can lead to five main conclusions. First, there is real value to be derived by the asset owner from the effective management of asset information. This helps to clarify doubts on whether there is a value in implementing BIM in AM. Second, the research points out that the value of BIM is not inherent but instead requires many other processes to deliver value to the organisation. The study has shown that there is the potential to execute different types of analysis with building automation systems, AInfM and BIM systems for asset optimisation, and that value lies at the end of the process. Third, the research identifies six dimensions of value that BIM contributes in AM, which are classified as: management, commerce, efficiency, industry, user and technology. Fourth, the study identifies the barriers to BIM implementation in an AInfM system. These factors play a role in the slow adoption of BIM in the operations and use phase. Finally, in terms of developing the BIMAsset VRM, the findings in this chapter have indicated that inputs, outcomes and the identification of nature of value impact BIM implementation and subsequent value realisation. The findings underscore the significance of incorporating elements in the BIMAsset VRM that cover: (i) the inputs to the BIM-based AM system; (ii) the observation of BIM-based outcomes in the form of management and operational maintenance KPIs; and (iii) the identification of any of the six typologies and nature (tangible and/or intangible) of BIM business value.

6.6 CHAPTER SUMMARY

This chapter focuses on the knowledge gap of identifying socio-technical approaches that deal with approaches to managing the information content of assets within a BIM-based AM system and how the information content drives value for the asset owners. The study investigates how asset information is collected, organised, stored, controlled, analysed, secured, shared and reported within a virtual AInfM system for strategic management-based decisions. A qualitative case study strategy is used to investigate the effective management of asset data in an AInfM system. Interviews and archival analysis are used to collect data. Thematic analysis and document analysis are utilised for data analysis. The study highlights three levels of effective AInfM; operational, tactical and strategic. The study identifies six dimensions of value that BIM contributes in AM, which are; management, commerce, efficiency, industry, user and technology value. The study highlights that the value of BIM is not inherent but would require many other processes to deliver value to the organisation. Finally, the study identifies the barriers to BIM implementation in an AInfM system and finds that the traditional business models of the AEC industry are a major reason for the slow adoption of BIM in AM. Finally, the findings in this chapter underscore the significance of incorporating elements in the BIMAsset VRM that cover: (i) the inputs to the BIM-based AM system; (ii) the observation of BIM-based outcomes in the form of management and operational maintenance KPIs; and (iii) the identification of any of the six typologies and nature (tangible and/or intangible) of BIM business value.

CHAPTER 7

BUSINESS VALUE OF BIM-BASED ACTIVITY SYSTEMS IN ASSET MANAGEMENT

7.0 BUSINESS VALUE OF BIM-BASED ACTIVITY SYSTEMS IN ASSET MANAGEMENT

7.1 CHAPTER INTRODUCTION

This chapter accounts for the study in relation to Research Objective 5: To investigate, identify and evaluate activity systems that drive BIM business value in AM. This chapter seeks to address one of the research gaps identified in Chapter 2. That is, the lack of understanding of key business processes that drive BIM business value during asset operations. Considering the research problem, this is a social (management or operational) and technical (BIM-AM systems) challenge that is two-fold. Firstly, asset managers are not clear on key business processes that BIM could enhance during asset operations, thereby limiting the tasks carried out using BIM. Secondly, there is insufficient evidence to show the efficacy of utilising the technological (BIM-AM) systems for AM tasks limiting their awareness. This lack of awareness has led to the slow adoption of BIM in AM and subsequent business value realisation. To address this research problem, four asset owners are involved in this multi-case study approach to achieve the research objective in identifying the key business processes that drive BIM business value. The business processes of these organisations are evaluated based on the tendency to derive BIM business value during asset operations. The rationale here is that the asset owner needs to understand the key activities or business processes that are responsible for driving BIM business value in AM. Therefore, there is a need to investigate aspects such as organisational strategy, BIM governance (people, process, technology), constraints and business process maturity as factors that would influence the attainment of an integrated BIM-based AM system by an asset owner. The findings in this chapter seek to guide asset owners to be able to understand the key business process to focus on to enhance and realise business value from BIM-based processes during asset operations. The importance of this chapter with respect to the development of the BIMAsset VRM is that it provides a better understanding of the justification that was made by the researcher for each of the identified elements and sub-elements. These findings are discussed and theoretically validated in Chapter 9.

7.2 RESEARCH JUSTIFICATION

BIM is transforming how buildings are designed, constructed and operated in the AEC industry (McArthur, 2015). These Digital Information Technologies (DIT) help facilitate the effective delivery of consolidated operational building performance data (Love *et al.*, 2013; McArthur, 2015). However, this area has not received much attention from researchers (Love *et al.*, 2014; Mirarchi *et al.*, 2018). AM involves a number of activities such as collecting asset information, planning asset maintenance, scheduling activities, managing inventory, data analysis and performance improvement. Collecting and analysing asset data using traditional methods for these processes consume a lot of time and effort. Therefore to effectively execute AM tasks, asset owners utilise DIT such as CMMS and IWMS, CAMS, Energy Management Systems (EMS), CAFM, IoT and BIM (Codinhoto and Kiviniemi, 2014; Guillen *et al.*, 2016; Love *et al.*, 2016). These programmes are designed to gather all related asset maintenance data, to enhance information delivery, risk mitigation and performance monitoring (Love *et al.*, 2016).

For the asset owner, the adoption of the right BIM and AM systems, techniques and strategies are vital for the achievement of business objectives. Poor AM practices certainly lead to challenging consequences as organisational goals are usually tied to the effective performance of key assets. A properly maintained asset will yield business value for an asset owner that exceeds that of a poorly maintained one. Effective access to the right information, at the right time, in the right format, against the right query, to the right department and by the right personnel is crucial in the efficient management of assets.

The utilisation of BIM has widened in scope, functionality, flexibility and interoperability to support the business processes of an asset owner (Love *et al.*, 2013). BIM has been proclaimed to deliver asset information for AM tasks in an efficient manner (Brous, Herder and Janssen, 2015). Love *et al.* (2014) suggest that BIM utilisation can enable strategic business outcomes for the asset owner. Furthermore, Brous, Herder and Janssen (2015) report that asset owners leverage data from their assets using BIM within their organisation and through the supply chain. However, the business value of BIM in AM are yet to be fully realised.

There are many challenges that hinder the realisation of value from BIM investments. Henderson, Pahlenkemper and Kraska (2014) claim that the AEC industry is replete with half-finished BIM systems that complicate processes without adding the value expected. Moreover, asset owners often believe that BIM systems will automatically drive business value and provide maintenance solutions without understanding that they are mere tools that facilitate effectiveness. Love *et al.* (2014) argue that the process of BIM implementation has to be managed proactively and that technology alone cannot deliver business outcomes.

Therefore, to identify BIM business value, there needs to be a concerted effort to research and identify the key business activities that drive business value in AM. There is a need for a process-oriented approach to evaluation that goes beyond the traditional boundaries of financial evaluation (Bakis, Kagioglou and Aouad, 2006; Love *et al.*, 2013). Hence, the need to identify and evaluate the key activity systems in AM in relation to BIM business value. Activity systems in this study are defined as the key AM business processes that drive business value for the asset owner.

7.3 CHAPTER 7 – DETAILED METHODOLOGICAL APPROACH

This study using a multi-case study approach to investigate and identify the activity systems that drive BIM business value in AM. Also, it seeks to evaluate the maturity of activity systems in relation to the organisational tendency of realising BIM business value. The appraisal of maturity is important because asset owners are not a set of homogenous organisations. They have varying levels of capability and maturity of processes during BIM implementation. As such, it is vital to relate the investigated BIM business value to their level of organisational maturity. The study will address the following research question:

- What are the vital AM business processes that drive BIM business value, and how do they relate to business process maturity?

7.3.1 RESEARCH METHODS

To achieve the research objectives, this study is exploratory and descriptive in nature (Saunders, Lewis and Thornhill, 2016). Exploratory research methods are utilised to identify the vital business processes that drive BIM business value in AM while descriptive research methods are utilised to convey the characteristics of BIM-based business processes in AM. Furthermore, the study adopts a multi-case study strategy (Yin, 2003). Based on this premise, the study first identifies the activity systems that drive BIM business value and then assesses them from single and multiple viewpoints in order to comprehensively evaluate the phenomenon.

This is a multi-case study research conducted on four large asset owners currently utilising BIM in their asset operations. Case Study 1 is a health sector owner-operator, which owns and manages about 125 buildings with over 280,000 m^2. Case Study 2 is an education sector client that owns about 378 buildings and maintains about 660,000 m^2. The research design is based on the cross-case assessment of four asset owners' business processes. Case Study 3 is a state-owned company that manages all public owned built assets and owns about 9,300 buildings with a total area of about 6,100,000 m^2. Case Study 4 is an owner-operator in the retail sector that owns about 2,000 built assets with a gross floor area of over 3,000,000 m^2.

The review of literature helped shape the theoretical framework for this study. The literature review identifies significant BIM governance factors of people, process and technology that are used as variables for the cross-case analysis. Furthermore, the literature review explores other aspects such as BIM business value, asset maintenance operations, including maintenance-based practices (Sections 2.4.1, 2.4.2, 2.7 and 7.2). Furthermore, the multi-case study is carried out in three stages, and they are; interviews, within-case appraisal, and cross-case analysis. Firstly, in-depth semi-structured interviews are employed for gathering data on aspects that impact BIM business value in the business processes of each asset owner. The outcome of this stage produces six activity systems that drive BIM business value through thematic analysis, which are found to be common in each case. The identified activity systems are BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management. The identified BIM governance factors and activity systems above form the basis for the development of the BIMAsset Maturity Model (BAMM), which is used to evaluate the four case studies in Section 7.5 and the development is presented in Section 8.4.3 and 8.4.4 of this thesis. Secondly, a within-case analysis is conducted for all the cases in order to appraise and score them independently using the identified BIM governance factors and activity systems. Finally, these cases are then compared against each other in a cross-case analysis, which highlights their individual business process maturity. The cases are then presented in the BAMM, which highlights their overall organisational maturity.

7.3.1.1 RESEARCH PROCESS: DEDUCTIVE REASONING SRQ-4

This section presents the methodological process of this part of the study. Here, deductive reasoning is applied for SRQ-4 to understand key AM business processes that drive business value for an asset owner and their relationship to organisational maturity. This aspect of abductive inference of the PRQ concerns the identification of six vital activity systems that drive business value. The research progression is shown in Figure 7.1:

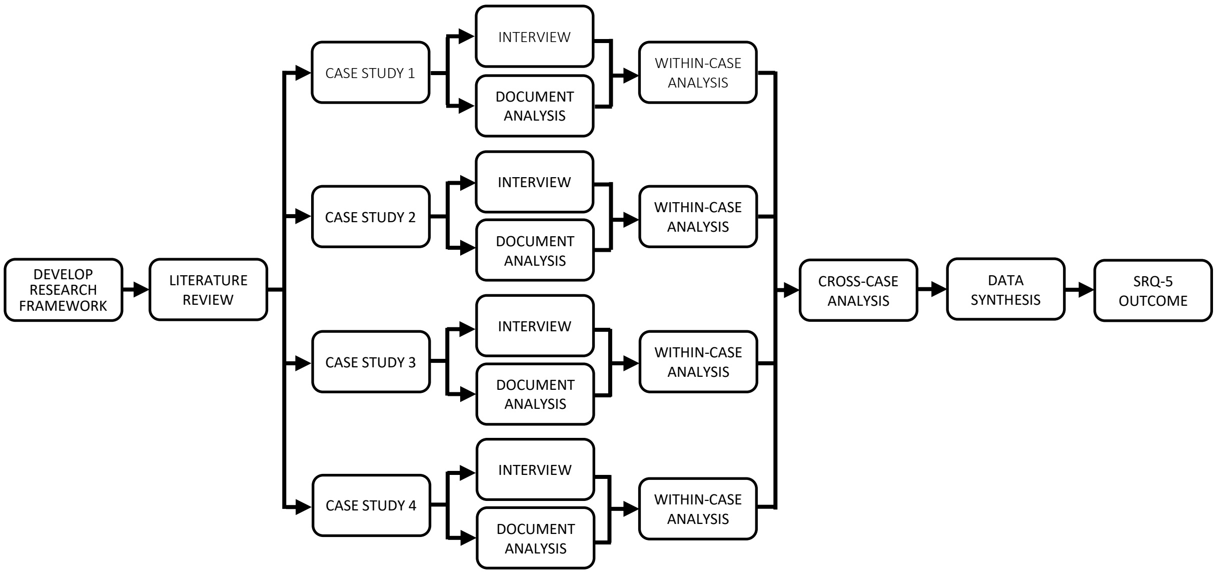


Figure 7.1: Deductive reasoning SRQ-4

7.3.1.2 CASE STUDY SELECTION

This study adopts a purposeful sampling strategy in case and respondent selection. Operational construct sampling is utilised, which is a type of purposeful sampling. All four case studies are selected purposefully and are asset owners that utilise BIM in asset operations. The criteria for selecting the case studies are: (i) they are experienced users of BIM; (ii) they have established processes of utilising BIM in asset operations; and (iii) they exhibit appropriate characteristics of BIM business value realisation. The selected participants for the study have the following characteristics:

- Participants have an advanced level of knowledge and understanding of BIM in AM.
- Participants are senior staff in charge of asset operations.
- Participants are high-level decision-makers in asset operations.
- Participants interacted with high, middle and lower-level personnel involved in asset operations.

The above criteria are designed to ensure that the selected cases are asset owners that have adopted BIM in AM in order to investigate vital AM business processes conducted using BIM and to facilitate easy comparison. To ensure validity, participant validation is conducted (Saunders, Lewis and Thornhill, 2016). This is achieved by sending transcripts and analysed data to participants for accuracy authentication. Furthermore, data validity is ensured by using multiple sources of data in the study (Patton, 2002).

7.3.1.3 DATA COLLECTION AND ANALYSIS

The study adopts qualitative techniques for data collection and analysis. This study utilises semi-structured interviews and document analysis to collect primary data. Four in-depth semi-structured interviews were conducted, namely one for each case study. The main purpose of the interviews was to elicit qualitative accounts of organisational BIM strategies, AM business processes, BIM value realisation activities and challenges of realising BIM business value. The NVivo™ software was used to transcribe and analyse the primary (Bazeley and Jackson, 2013; Saunders, Lewis and Thornhill, 2016). Coding is utilised for easy analysis, and the indexing and retrieval of primary data (Boyatzis, 1998). These codes are classified into categories and further linked to the study themes. The primary data categories comprise one or more codes, which are used in the data analysis and discussion. Furthermore, thematic analysis, as a qualitative research technique, is used to facilitate the identification, analysis and reporting of themes within the study data (Boyatzis, 1998). During the literature review, themes were established, which guided certain aspects of the data analysis. Documents related to organisational protocols, strategies, standards and value realisation management activities are sourced from participants in order to further investigate the phenomenon. Document analysis is conducted, and findings are reported alongside the interview findings in Section 7.4 (within-case analysis). Furthermore, to analyse the four case studies, a cross-case analysis method is used. This study utilises a case study assessment sheet, which is presented in Section 7.5 and the development presented in Section 8.4.4. Figure 7.2 shows the data analysis process in this study.

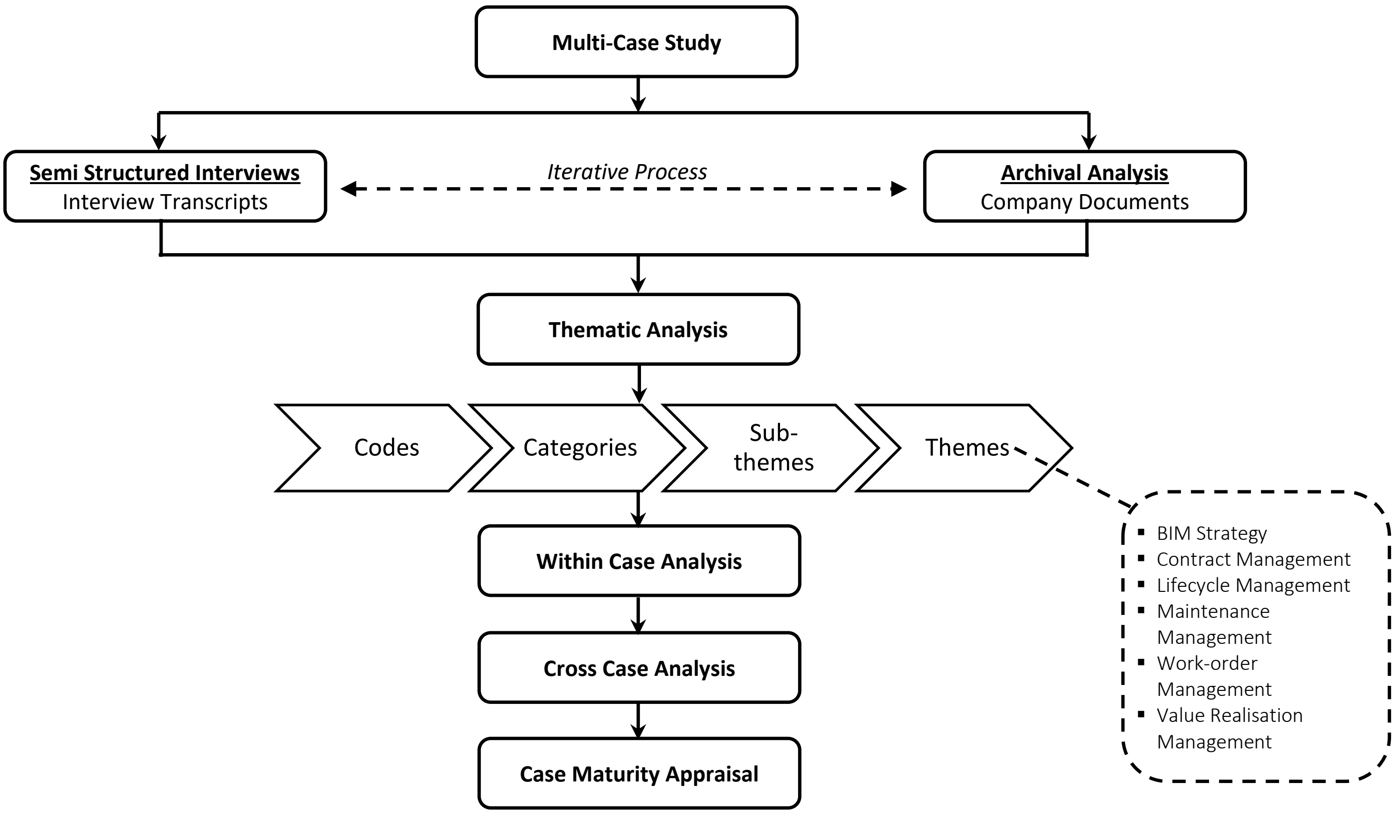


Figure 7.2: Multi-case data analysis process

7.4 RESULTS: WITHIN CASE ANALYSIS

From the data collection and data analysis exercise, the study identifies six main organisational activity systems that drive business value for an asset owner. They are; BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management. The four case studies are appraised based on these activity systems. BIM strategy as an AM activity system involves the overall organisational policy in employing BIM in planning and directing asset operations and management. The AM activity system of contract management involves organisational oversight and implementation of BIM-based processes in the creation, negotiation, analysis, performance monitoring, risk management and full execution of contractual obligations while minimising risk and maximising financial and operational performance. Lifecycle management is an activity system which involves the organisational use of BIM in all successive stages involved in asset development, that is, from inception to disposal. The activity system of maintenance management is centred around the effective management of resources and systems with the aim of checking compliance, controlling costs and optimising efficiency using BIM-based processes. Work-order management as an AM activity system involves the comprehensive organisational approach towards utilising BIM-based processes in creating, scheduling, updating, budgeting, analysing, prioritising and tracking of work-orders. Lastly, value realisation management as an AM activity system that involves the establishment of organisational processes for the definition, planning, identification, monitoring and realisation of BIM business benefits within the organisation and across different stages of the lifecycle.

7.4.1 CASE STUDY 1

7.4.1.1 SUMMARY OF THE CASE

In this case study, the department that maintains physical and built assets in Company B is investigated. This organisation is an owner-operator in the US that utilises BIM in the management of its assets in the operations and use phase. Company B is a health sector client, which owns and manages about 125 buildings with over 280,000 m^2 of floor area. At the strategic level, the department is involved in identifying innovation in asset operations and designing strategies for their implementation. At the operational level, the department is responsible for all daily operations for the infrastructure, physical buildings and plants on a 24-hour basis. Company B utilises BIM in asset operations since 2010. They mainly use a robust CMMS, which has a plug-in for 3D spatial data. The CMMS also connects to other DITs in different departments of the organisation. Company B utilises BIM in 100% of its asset maintenance or service requests but only for the newly built assets that have been designed and constructed using BIM. Other capital investments go through the standard CMMS processes.

7.4.1.2 OVERVIEW OF COMPANY B BIM STRATEGY

Company B has a dynamic strategy towards the implementation and utilisation of BIM in their organisation, they are (Figure 7.3); (a) Usability and safety; (b) Data maintainability; (c) Data Accuracy; (d) Speed and reliability; (e) Flexibility and predictability. To achieve these business objectives Company B has engaged in: (1) Lifecycle approach from design to operations; (2) Defining the requirements from the construct of BIM; (3) Developing new systems and business processes; (4) Developing bilateral exchange relationship between CMMS and the digital twin (real-time building information model); and (5) Partnering in software development.

Firstly, Company B utilised Integrated Project Delivery (IPD) to break down their vertically stacked departments that do not communicate effectively during project delivery to ensure a lifecycle approach. This strategy had to be adopted because, in the past, Company B was under pressure to run facilities that the operational personnel knew little about because the construction team were handing over the data and buildings on the same day. Currently, the operational department in Company B are participating in project development meetings in order to make contributions in design and specifications that will make the buildings more usable, safer and reliable.

Secondly, Company B discovered early in the BIM process for the need of established BIM standards. In line with this realisation, they have developed a user requirements template for specifying the output of the construction contract so that the data coming out of the building information model is predisposed to gain insight through their CMMS. The information requirement template specifies all the statutory submittal data, operations data, preventative and predictive maintenance data, manufacturer data, serial numbers, nameplates, operating temperature ranges, frequencies, belt sizes, and including the more granular operational data.

Thirdly, Company B is disposed to a bilateral communication between the CMMS and the interpretation of the digital twin, which is a living as operated model that comes out of the construction project. This strategy has been adopted in making changes to the digital twin or CMMS, depending on whether it is geospatial or simply data over time to keep the living as operated model current or live. This strategic approach helps to design a bilateral exchange or relationship between the CMMS as an interpretive tool and the building information model, where the two can read and update each other as changes are made to one or the other.

Fourthly, Company B has automated all its maintenance activities through the CMMS. The aim of this exercise is to reduce the vagaries in that amount of process touch points because in the old system a call-centre service would enter a work-order for the operational personnel, and then it goes to the CMMS. The new system has three advantages; (a) it is active 24-hours a day; (b) the service request gets passed to the responsible trade specialist within seven seconds; (c) the system is efficient and reliable. At implementation, Company B had 73% electronic receipt of work-order versus 27%, which were to the call centre. Currently, they have 92% electronic receipt and 8% to the call centre.

Fifthly, Company B has identified strategic opportunities of partnering with stakeholders in the industry. They have agreements with multinational corporations that collect data from their equipment. The purpose is to gain access to the operational parameters of assets out of a global sample in order to identify optimum conditions of operating the equipment. That is, the most efficient and sustainable methods, and to develop predictive ranges of operation so that the asset will alert operational personnel when it is falling out of range so as to remedy it before failure. Also, Company B is involved in a clever proposition of software development and programming to develop plugins with a major CMMS and BIM software provider. This decision is taken because Company B acknowledged that the market is underdeveloped for BIM utilisation in the operations and use phase. The business advantage of this proposition for Company B is that they will take ownership of the software after development.

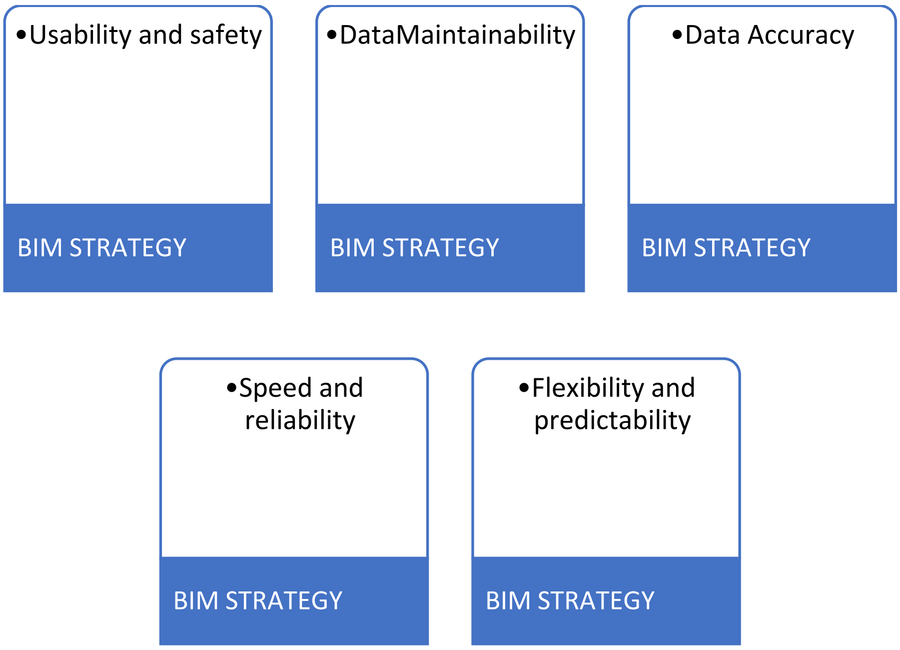


Figure 7.3: Company B BIM Strategy

7.4.1.3 BIM BUSINESS VALUE IN COMPANY B

7.4.1.3.1 CONTRACT MANAGEMENT

Contract management is the least developed activity system in Company B. This is due to the organisational structure, where usually asset maintenance is carried out by in-house personnel. Company B has highlighted that they are yet to roll out services for monitoring contracts using the BIM and CMMS.

7.4.1.3.2 LIFECYCLE MANAGEMENT

Utilising BIM in the operations and use phase enables Company B to break the silos of disciplines within the organisation to conduct full-circle planning. That is, cradle to grave design, programming, operations, and lifecycle management of facilities. This allows stakeholders in the operations phase to participate and contribute not only during design development but to validate as-built data, populate the work-order system, and develop a preventative maintenance strategy. Also, the asset knowledge database from the BIM systems enables facility condition assessments and planning through data, from which long-term strategic plans are drawn. These plans are submitted to the board for approval. Another aspect that is of value to Company B is in a case where the operational department ensured that flags of 600 x 600 mm grids were built in the designs to ensure that no structures were assigned in those areas. All the designers had to work their designs around them and were instructed to locate serviceable parts and devices adjacent to the working spaces. This was a practical solution to an operational problem because, in Company B, it took a lot of time and effort in locating and determining where and how to access an area to perform a fix. But with this solution, the operational personnel have found tremendous time savings in executing service requests through a lifecycle design approach.

7.4.1.3.3 MAINTENANCE MANAGEMENT

Company B utilises BIM for maintenance management to analyse and query data by evaluating KPIs of various user groups or stakeholders within the organisation. The use of these systems enables Company B to identify and establish normal operating parameters for assets and to detect one that is falling out of range. Hence, this capability has enabled the asset maintenance strategy of Company B to become mature and more predictive than reactive. Company B termed the value proposition of BIM in asset operations as '*absolutely certain*' that BIM would reduce the number of their failed asset interventions when it is fully rolled out on the whole asset portfolio. Furthermore, the CMMS enables Company B to answer simple queries such as:

- What is the amount of work-orders that are outstanding?
- How many are critical versus second priority?
- What are the completion rates?
- What is the average completion timeline?

These KPIs are used for reporting from the operational level to strategic management within the organisation. Also, Company B is using other DITs for enhancing its maintenance strategies such as partnering with a major multinational corporation to public-source asset data for optimisation. Additionally, due to the nature of Company B being a health sector client, there are regulatory standards on requirements for preventative maintenance to be done according to manufacturers' recommendations. With BIM and CMMS, Company B is collecting large amounts of data which allows them to make some changes to manufacturers' recommendations on preventative maintenance. Without reliable and accurate asset data coming from the BIM systems, there may not be enough evidence for Company B to justify such actions to the regulators. Another benefit that Company B derives is better management of maintenance activities in the allocation of workload for operational personnel. Using the BIM systems, the asset manager can search by asset, inventory, work-order completion rate or outstanding tasks that have been allocated to each operational personnel or team. This gives a good picture of the workload allocation of the operations department in Company B.

7.4.1.3.4 WORK-ORDER MANAGEMENT

Another aspect of BIM business value in Company B is work-order management. The automation of the system in Company B has improved efficiency, data accuracy and reduced time of operations. In Company B, there are three ways for end-users to set up work-orders, these are; through the CMMS portal, CMMS mobile app and call-centre. Using the CMMS portal and mobile application, end-users can access the building model in 3D-view, highlight a faulty asset or equipment, and raise a work-order. With the call centre, the end-user will have to pass on the complaints, which will be logged into the CMMS on their behalf. Once the work-order is raised, the system automatically generates all the information associated with the selected asset or equipment. This query moves through the normal process of executing service requests but is managed virtually with reference to the 3D building information model. Every work-order entered into the system has a historical record in the database. The completed tasks are then reported to regulatory authorities to demonstrate compliance.

7.4.1.4 COMPANY B BIM BUSINESS VALUE REALISATION MANAGEMENT

Company B has strongly emphasised the importance to establish value realisation as a business process and to validate BIM business value within the organisation. They are currently in the process of formalising the business value derived from BIM by documenting them in strategic reports and developing business cases that prove an ROI. Company B has acknowledged that without providing the validation to senior management that there is real business value in BIM during asset operations, it may be difficult to roll-out BIM across the whole portfolio. Company B highlighted an instance where the use of BIM saved an estimated $40,000 and approximately 65 man-hours in a single maintenance task. In this case, Company B had a leak which from historical records was estimated to cost about $40,000 and 72 man-hours to fix. Traditionally, Company B would have to retrieve paper plans from the archives to perform a fix like this. Another complication was that they would have to drill many holes in a fire-rated shaft in trying to find the source of the leak, and that remedying them would be incurring substantial costs. Albeit, by using the BIM systems and running the digital twin, the operational team were able to locate the leak from a domestic cold-water line near a vertical structural steel fire-rated shaft. During the diagnosis, the operational team followed an elimination process of first identifying water contingents on each floor that link to the chase through the digital twin, and then isolating them individually until the leak was detected. Company B was able to diagnose the leak in 90minutes, and the plumber was called to fix the leak. The whole fix took 7 hours, and that section of the building opened up for business the next day.

Company B are currently in the process of formalising the business value derived from BIM by documenting them in strategic reports and developing business cases that prove an ROI. They have acknowledged that the organisation had gone beyond the point of adopting an innovation just because they perceive it to be beneficial to their business processes, but also, they have to justify and validate those use cases.

7.4.1.5 CHALLENGES OF BIM BUSINESS VALUE REALISATION IN COMPANY B

The study identifies the following challenges in Company B they are; workload in inputting data needed for asset operations; managing data within the asset models; and developing measurable metrics for BIM business value.

7.4.1.5.1 WORKLOAD IN INPUTTING DATA NEEDED FOR ASSET OPERATIONS

Company B recognises an increase in workload as a result of the data delivery requirements where stakeholders are requested to input nomenclature, omniclass, family, including other standards that the data needs to conform to coming out of the design and construction stages. In some cases, this has received some push back from the design and construction delivery stages, where the architects, contractors, subcontractors, tradesmen have been used to the traditional methods. These cultural changes have impacted on stakeholders in the design, construction and operational phases in the development of the building information models. Furthermore, Company B admits that the major barrier is getting the data for day-to-day tasks in a format that is consistent with organisational standards and is familiar to the existing building engineers. The above assertions accord with existing literature (Kivits and Furneaux, 2013; Bosch, Volker and Koutamanis, 2015).

7.4.1.5.2 MANAGING DATA WITHIN THE ASSET MODELS

Company B highlight the challenge of filtering through a large number of datasets. They acknowledge that there is so much data that needs to be pared down. To achieve this, Company B’s operational data requirement is only 5% of the entire data contained in the building information model. Data on the other 95% is important but not required for day-to-day operations. Despite this development, there are still challenges in selecting the data threshold that is manageable. The above assertions accord with existing literature (Lin, Gao and Koronios, 2008; Brous, Herder and Janssen, 2015; Krämer and Besenyoi, 2018).

7.4.1.5.3 DEVELOPING MEASURABLE METRICS FOR BIM BUSINESS VALUE

Another challenge for Company B is developing measurable metrics for BIM business value. Company B highlight the difficulty of creating metrics, which would allow the organisation to measure performance, and subsequently find out where the problems are. There are so many KPIs produced by the systems, but the challenge is being able to relate the performance indicator to an operational outcome in business value terms. The above assertions accord with existing literature (Love *et al.*, 2013; Codinhoto and Kiviniemi, 2014; Love *et al.*, 2014).

7.4.2 CASE STUDY 2

7.4.2.1 SUMMARY OF THE CASE

Company C is an asset owner from Denmark that utilises BIM in building maintenance management. Company C is an education sector client. The department under investigation in Company C is responsible for planning, design, construction and operating facilities. As a regulation in Denmark, all public sector projects have to use BIM as the data foundation for collaboration and communication of project deliverables. At the strategic level, the department is responsible for designing and implementing strategies for planning, coordination and communication within the organisation during project delivery. At the operational level, the department is responsible for operating the built assets. Also, the department acts as data translators for the operational department in the way and manner they request, receive and utilise information for current and future operations. Company C owns about 378 buildings and maintains approximately 660,000 m^2 of built floor area. Company C utilises a CMMS with a BIM plugin for 3D functionality to manage its assets. Asset maintenance for already digitised assets are managed through these systems in Company C.

7.4.2.2 OVERVIEW OF COMPANY C BIM STRATEGY

Company C has many objectives for implementing BIM in the operations and use phase. These centre around the systems integration, quality of data and flexibility of systems and quality of data for business processes in the operational department. An approach to Company C's BIM strategy is linked data. They recognise that BIM cannot contain all the data required for asset operations, and they perceive BIM as a medium for linking data. Company C is working toward systems integration where data can be linked and integrated to enable operational personnel to find the data needed to enhance their business processes. Company C has partnered with a software provider to develop systems that would be flexible to their business processes. The decision to have a technological partner arose as a result of the technical limitations of existing software in the market place. Hence, Company C selected a mid-sized company that would respond quickly to their demands. Furthermore, Company C acknowledges the iterative learning process of utilising data in managing assets as they have developed an in-house data requirement template for day-to-day operations. These requirements are stated in their contracts, and they define how AM data should be delivered from the design and construction processes.

7.4.2.3 BIM BUSINESS VALUE IN COMPANY C

7.4.2.3.1 CONTRACT MANAGEMENT

The BIM systems in Company C perform functions for contract management. The planned preventive maintenance system contains a contract database, which stores data for all external companies that have been engaged by Company C for a service. This system keeps records of the operations and helps track payments. Whilst performing this function the systems form the company and contract database. Also, Company C has a ticket system for contracts management which is developed in-house. This system is used by Company C and its suppliers.

7.4.2.3.2 LIFECYCLE MANAGEMENT

Company C utilises BIM for long-term planning for its facilities. The system has a financial tool that is used to allocate funds and plan organisational resources for annual planned preventive maintenance activities. Data is used for forecasting and planning of maintenance activities in order to apply for funding to senior management.

7.4.2.3.3 MAINTENANCE MANAGEMENT

Company C utilises BIM for maintenance management in the operation of its assets. The BIM and CMMS platform has many functionalities, one of which is a container of data. It has a room database, building database, document database and contract database, all of which can be utilised for activity management in planning preventive maintenance. This helps Company C to integrate information and rooms or spaces, and to enable operational personnel to find out what kind of information is needed for a specific activity in any built asset. Company C highlights that with BIM systems, they can now plan their maintenance activities cleverer. Also, the use of BIM systems has impacted on a new culture of planned preventive maintenance in the organisation and Company C is planning on expanding its planned preventive maintenance strategy.

7.4.2.3.4 WORK-ORDER MANAGEMENT

The BIM systems in Company C contain all geometric information, including room database, which is extracted to the CMMS whenever there is an active service request. Alternatively, the operational personnel can use the help desk, which is a ticket system for raising work-orders. Every department plans its own activities and manages them independently. Team members change the task status on planned preventive maintenance tasks accordingly as the activity progresses.

7.4.2.4 COMPANY C BIM BUSINESS VALUE REALISATION MANAGEMENT

Realising BIM business value is obviously one of the weaknesses of Company C. Formally, the organisation has not established any formal processes of measuring or validating BIM business value. Rather they view BIM as a strategic solution to their complex coordination, communication, and data management problems. Company C asserts that the use of BIM is necessary for coordinating different building models from the disciplines of architecture and engineering during the lifecycle development of assets. Company C acknowledges the organisational weakness of measuring business value and attributes it to the implementation strategy of BIM in the organisation, which is bottom-up. In general, there exist testimonies of the positive impact of BIM, but Company C has not documented them in a systematic way. Company C has only attempted to validate digital deliveries from construction to the operational phase in terms of workflow benefits.

7.4.2.5 CHALLENGES OF BIM BUSINESS VALUE REALISATION IN COMPANY DC

The study identifies the following challenges in Company C, and they are; technology maturity; change management strategy; and difficulty in translating operational instances.

7.4.2.5.1 TECHNOLOGY MATURITY

Company C identifies technology maturity as one on the main barriers for realising BIM business value in the operations and use phase. They assert that there have been challenges in the availability of functionalities for AM or FM business processes in the global market. Company C highlight the lack of advancement of tools in comparison to those available for the design and construction phases. They claim that with the availability of more tools and functionalities that would simplify tasks, operational personnel would derive more value from BIM. The above assertions accord with existing literature (Codinhoto and Kiviniemi, 2014; Fregonese *et al.*, 2015).

7.4.2.5.2 CHANGE MANAGEMENT STRATEGY

Company C recognises the bottom-up approach to BIM implementation to be a barrier in realising BIM business value in the organisation. This is because there is a vacuum of management responsibility and lack of sufficient focus in driving the BIM initiative and communicating organisational objectives for and how to implement BIM. Company C highlight that for change to be effective, the BIM implementation strategy has to be a bullet point on the management agenda. This is because if it is only from bottom-up, then the change initiative loses strength and credibility across the organisation. However, in using the bottom-up strategy, Company C has established BIM change ambassadors that consult internally on the needs, values and benefits to be derived from BIM and communicate the same to the top management. The above assertions accord with existing literature (Becerik-Gerber *et al.*, 2012).

7.4.2.5.3 DIFFICULTY IN TRANSLATING OPERATIONAL INSTANCES

Company C experiences challenges in translating classifications like object families to instances in the operations and use phase. This is because the structure of data use in the design phase is very different in relation to asset operations. Company C assert that a classification system represents many unique attributes, and a single class may have hundreds of different values. This presents a huge challenge in translating classifications to operational instances.

7.4.3 CASE STUDY 3

7.4.3.1 SUMMARY OF THE CASE

The second case study is a department in Company E, which is a Finnish owner-operator that utilises BIM in building asset operations. This is a state-owned company that manages the public-owned built assets. At the operational level, the department is responsible for maintaining the public-owned buildings and providing a functional, safe and supportive work environment. Company E has mandated the use of BIM in all of its projects with a value above €2m since 2007, and by 2018 the limit was reduced to €1m. At the strategic level, the department is responsible for developing the organisational BIM requirements, which later formed a key component of the COBIM 2012 standards of Finland. At the operational level, the department is responsible for the effective running of their physical assets. Company E owns about 9,300 buildings and maintains about 6,100,000 m^2. Company E is proud of an innovative organisational culture that constantly seeks for new solutions to improve their business processes. Company E plans to leverage on BIM, IoT, CMMS, Augmented Reality (AR), Virtual Reality (VR) and the like in managing its built assets. Company E manages 100% of its maintenance activities through these systems.

7.4.3.2 OVERVIEW OF COMPANY E BIM STRATEGY

Company E has an asset digitalisation programme which aims to: (a) Develop solutions that provide real-time, automated information for decision-making, space management, asset maintenance and service delivery; (b) Enhance the efficiency of operations and improve quality delivery; (c) Develop the understanding and correlation of phenomena related to energy consumption, indoor conditions and user satisfaction; (d) Improve the indoor conditions and increase end-user productivity; and (e) Provide new services for users and enable conducive indoor conditions in the workplace (Figure 7.4). Company E has focused on new business processes and the digitalisation of maintenance operations of their facilities. The aim is to enhance space and asset management processes by introducing new digital tools and operating models. Through the digitalisation program, Company E seeks to respond to the changing work environment by increasing workers' ability to influence their own work environment positively. Also, the strategy seeks to increase the understanding of technical staff in knowledge of built asset-related phenomena.

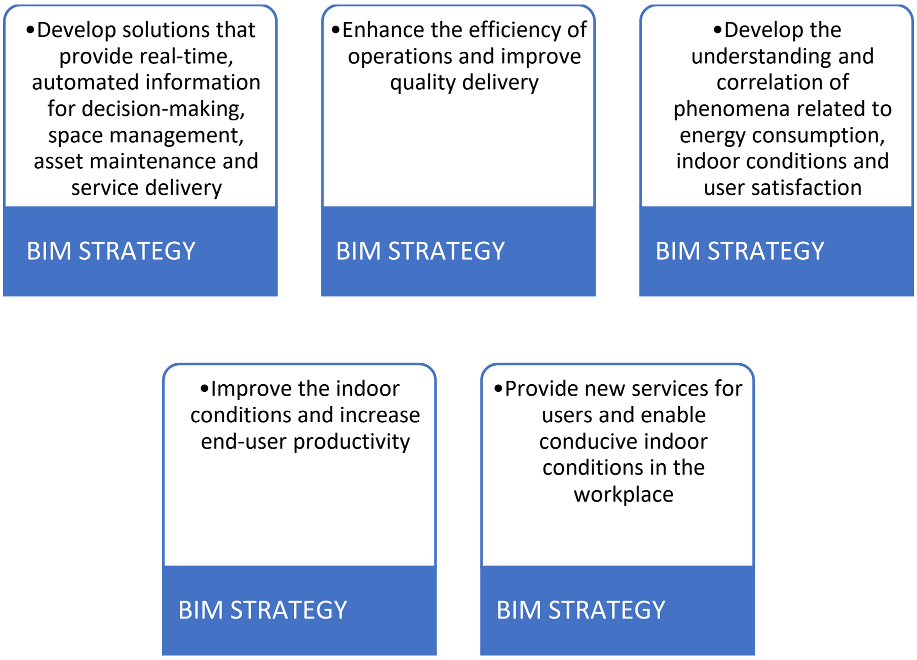


Figure 7.4: Company E BIM Strategy

7.4.3.3 BIM BUSINESS VALUE IN COMPANY E

7.4.3.3.1 CONTRACT MANAGEMENT

Company E has a fixed process for contracts development, where they have a pre-approved list of maintenance service providers. The process is fully automated using the BIM systems right from tender to handover and is used for tracking payments as well. Company E uses cost-plus-incentive contracts, which allows for the negotiated fee to be adjusted by a formula based on the success of the service request. The BIM systems in Company E are used throughout the whole process to measure the performance of maintenance service providers based on set KPIs. If a contractor's performance is good, Company E will pay more, and if customer satisfaction is low or if service requests are not completed on-time, part of the contractor's fee will be taken off. The use of BIM systems in Company E has enhanced communication within the organisation and across the supply chain in project delivery.

7.4.3.3.2 LIFECYCLE MANAGEMENT

Company E utilises BIM-based asset data in lifecycle planning of their facilities. Here, Company E derives business value from BIM-based asset data, which is used in the planning of annual maintenance plans. These plans are usually based on historical records of maintenance, energy consumption, service request and the like. Planning through data enhances knowledge about the historical operations of facilities, thereby, informing future planning decisions on built assets. Furthermore, as assets undergo renovations or alterations, the BIM systems are utilised in planning space usage to make assets more efficient and to increase their annual yield in the long-run. Another aspect that feeds into decisions in lifecycle management is customer satisfaction. Company E utilises BIM systems in planning the work environment to support wellbeing and productivity by enhancing the working conditions.

7.4.3.3.3 MAINTENANCE MANAGEMENT

Company E has utilised BIM for over 17 years in project delivery. Therefore, the use of BIM is crucial to their business processes. Company E manages all of its maintenance activities through BIM and other DITs. They have termed it as '*impossible*' to work without existing BIM systems because of the level of dependency in managing the large datasets that each building produces considering their huge portfolio, which is about 9,300 built assets. Company E has many databases for maintenance management, for example, maintenance project database, building basic information database, energy management database, CMMS, etc. Company E has derived business value of BIM in maintenance management through reduced routine work times and improved predictability of asset failure. The use of BIM has enhanced the ability of asset managers in monitoring the work environment for space users. Furthermore, another benefit is the monitoring and analysis of indoor conditions using Artificial Intelligence (AI) applications that are further integrated with other DITs and linked to building information models. Maintenance requests, approvals and maintenance monitoring are all automated. Furthermore, these systems have analytics that are used to detect and calculate deviations in asset performance for corrective measures to be taken when necessary.

7.4.3.3.4 WORK-ORDER MANAGEMENT

Another activity that derives BIM business value in Company E is work-order management. Company E utilises a CMMS in monitoring its work-orders. Through these systems, work-orders can be raised, processed, monitored and summaries reported to senior management for strategic decision-making. Within any period of choice, Company E can track how many service requests have been initiated, how soon they have been completed and how many are still open. With this, work-order performance within the organisation can be measured. These systems make it easier to troubleshoot, monitor service requests, feedback, speed up action, reduce idleness of equipment and improve task performance.

7.4.3.4 COMPANY E BIM BUSINESS VALUE REALISATION MANAGEMENT

Company E puts into practice one method of value realisation, which is the annual customer satisfaction poll it conducts. In this poll, end-users are asked to give feedback on details about the building they mainly work in. This survey poll is web-based containing several questions, each with a 1-5 Likert scale. Every response below 3 is allocated a textbox for more information. The response rate of these questionnaires average 8,000 replies annually. The poll results give Company E valuable information about how well they have performed in maintenance activities. Also, the KPI results are used to calculate the end-user experience during the calculation of the contractor’s incentives. The KPIs measured by the online surveys cover aspects of safe, healthy and productive working environments, especially in maintaining indoor air quality at high levels when the spaces are in use. Furthermore, Company E utilises end-user data and combine them with results from technical audits to find a correlation between the two aspects and to conduct further analysis of BIM business value contributions. In addition, the results are used as a development tool to improve future actions. This is how Company E tracks the value of BIM in their business processes.

7.4.3.5 CHALLENGES OF BIM BUSINESS VALUE REALISATION IN COMPANY E

The study identifies the following challenges in Company E, and they are; various versions of BIM authoring software; lack of standards or requirements for asset operations; establishing as-built models; lack of systems integration; utilising data points and quality of information.

7.4.3.5.1 VARIOUS VERSIONS OF BIM AUTHORING SOFTWARE

One of the challenges of utilising BIM in the operations and use phase is the different versions of BIM authoring software. Company E has been an early adopter, and one of their bottlenecks is making changes to the building models 10, 20, 30 years later, when there is a need to renovate the facility. The authoring software have many generations, and this is a barrier for editing models that have been saved in previous versions. Currently, Company E has over 150 building models in their repository. They have realised that they are not able to make changes to some of the models. Hence, the solution to problems like these is that Company E will have to remodel those buildings from scratch. The above assertions accord with existing literature (Becerik-Gerber *et al.*, 2012).

7.4.3.5.2 LACK OF STANDARDS OR REQUIREMENTS FOR ASSET OPERATIONS

Company E highlights the lack of established BIM standards and procedure in the AEC industry as a barrier to implementation. In comparison with the design and construction stages, the operations and use phase is lacking in standards (Becerik-Gerber *et al.*, 2012). Company E emphasises that it is necessary for the AEC industry to develop requirements for BIM-based data from the construction process and standards for utilising BIM in the operations and use phase in order to fully realise the business value that BIM brings. This is because without standards asset owners cannot utilise BIM in AM and FM tasks, and as a result, they will be losing value from the investment made in developing building models from the design and construction stages. The above assertions accord with existing literature (Becerik-Gerber *et al.*, 2012; Kiviniemi and Codinhoto, 2014).

7.4.3.5.3 ESTABLISHING AS-BUILT MODELS

Another challenge of implementing BIM in the operations and use phase in Company E is having as-built models that are accurate. This is because many changes that have been executed during a construction project are not updated in the original files. Company E does not have established processes for checking and updating the as-built models. Once the as-built models are submitted by the contractors, there are no designated schedules for operational staff to check for compliance. During their recent audit as part of the digitalisation program, Company E has found some of the CD-ROMs containing building models of their facilities to be empty. The above assertions accord with existing literature (Eastman *et al.*, 2011; Patrick, Munir and Jeffrey, 2012; Bosch, Volker and Koutamanis, 2015; Kassem *et al.*, 2015; Krämer and Besenyoi, 2018).

7.4.3.5.4 LACK OF SYSTEMS INTEGRATION

Company E has used various BIM systems and DITs in asset operations, and some of the systems have integration challenges. In some cases, operational personnel in Company E have to manually update three different systems, which is the CMMS, energy EMS and Property Management System (PMS). The above assertions accord with existing literature (Becerik-Gerber *et al.*, 2012; Codinhoto and Kiviniemi, 2014; Pärn, Edwards and Sing, 2017).

7.4.3.5.5 UTILISING DATA POINTS AND QUALITY OF INFORMATION

Company E utilises several IoT devices to collect data from their buildings, and one challenge is in identifying uses and business value of data coming from these source points. Also, guaranteeing the quality of information is another challenge. Company E has attempted to conduct some analysis from their building information models and historical maintenance data, but they found out that some of the data is incomplete. Also, in some cases, the datasets lack historical maintenance activities that have been carried out. As a result, the building models lack important meta-information such as real envelopes, the start of the project date, end project date, and the like. Company E attributes their inability to properly track and document changes to the large size of their portfolio. The above assertions accord with existing literature (Lin, Gao and Koronios, 2008; Domingues *et al.*, 2016; Zadeh *et al.*, 2017).

7.4.4 CASE STUDY 4

7.4.4.1 SUMMARY OF THE CASE

The first case study is a division of Company F, which is located in the UK that utilises BIM in maintaining its physical and built assets. Company F is an owner-operator in the retail sector. At the strategic level, the department is responsible for identifying technologies, new ideas and new ways of working within the business. At the operational level, the department is responsible for project management in terms of setting out timelines, managing tasks, people management and servicing the teams that manage other projects all through the business. Company F owns about 2,000 built assets with a gross floor area of over 3,000,000 m^2.

Company F as an owner-operator, utilises various systems across the business to manage its assets. It utilises AM systems, BIM systems and other DIT. Company F utilises these technologies to manage all its physical assets, including building fabric maintenance. Every asset maintenance carried out by the organisation is managed through these systems. Company F also utilises these systems to track costs and payments to contractors on the commercial side of things.

7.4.4.2 OVERVIEW OF COMPANY F BIM STRATEGY

Company F has many objectives for implementing BIM in their AM and FM processes that are centred around the quality of the information received from individual assets during work-order requests. Company F understood that the quality of information received from building managers was not sufficient. So, they conducted business process reengineering to address this issue. Company F modified its processes so that the building managers called-up a help desk to log in their work-order requests. This ensured that the managing agents collected the required information around any work-order request.

7.4.4.3 BIM BUSINESS VALUE IN COMPANY F

7.4.4.3.1 CONTRACT MANAGEMENT

The commercial team of Company F utilises BIM in managing their master invoicing system. This helps asset managers and facility managers document the contract processes and allow them to reference invoices against stages of the asset lifecycle. This assists in tracking payments throughout contract administration.

7.4.4.3.2 LIFECYCLE MANAGEMENT

Company F derives business value from BIM in the lifecycle management of assets. These systems and processes enable the development of a database, which builds up a lifecycle history of asset maintenance. This database enables asset managers and facility managers within Company F to effectively manage maintenance budgets as well as capital replacement funds through the provision of reliable information in the maintenance of assets. This database helps support other asset information contained in separate BIM and AM systems, which in turn informs capital asset replacement.

7.4.4.3.3 MAINTENANCE MANAGEMENT

BIM in Company F helps support and enhance planned maintenance. Various systems and software are utilised during maintenance management. The systems help schedule, monitor, manage and report asset maintenance activities. Company F has derived value from BIM through efficient information management and better use of time in making Service-Level Agreements (SLAs) and keeping contractors accountable to those agreements. Thereby making operational and contractual mean time between failures (MTBF), mean time to repair (MTR) or mean time to recovery (MTTR) easily trackable. Another benefit to these systems is the utilisation of sensors by Company F to monitor asset condition across different locations through the development of automated control rulesets. Once the data coming from the sensors do not comply with the rulesets, an alarm with a corresponding work-order is automatically generated by the BIM system for the asset manager to attend to. Furthermore, the BIM systems help predict asset failure, and at the strategic level, it helps resource planning in tasks such as engagement of contractors, scheduling work-orders and task time management. In general, these systems help reduce the frequency of asset failure by enhancing planned maintenance within the organisation.

7.4.4.3.4 WORK-ORDER MANAGEMENT

Another activity conducted by Company F is to develop standard operating procedure documents around their activities. These templates provide information to operational staff, starting from the need of the document itself through to what problem it solves. These documents provide information on the systems, asset data and resources required for task execution to operational staff. All these processes are allotted with timescales for action during task execution. These timescales vary depending on the nature of the work-order and the type of SLA required to execute that task. An example of a standard procedure document is explained in Figure 7.5, which gives information for managing a work-order in Company F.

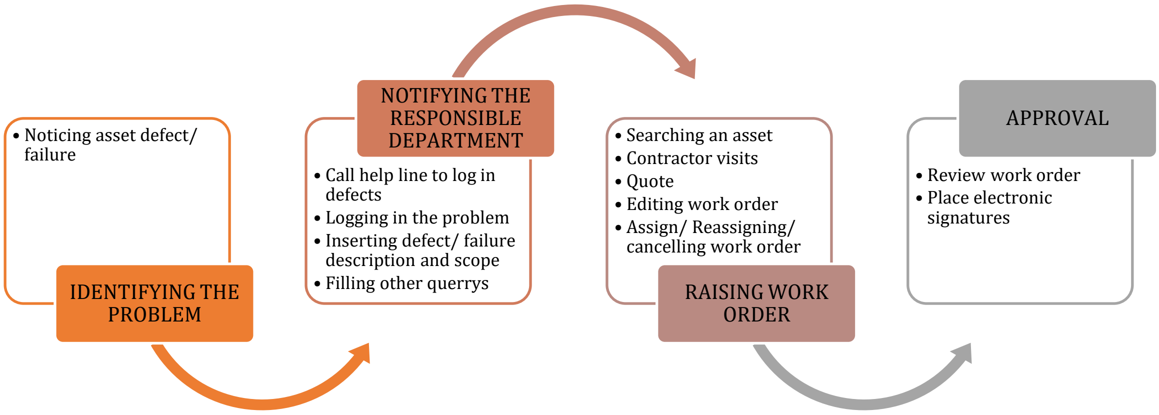


Figure 7.5: Work-order management

7.4.4.4 COMPANY F BIM BUSINESS VALUE REALISATION MANAGEMENT

Company F puts into practice several methods in justifying innovations such as BIM. An innovation refers to '*the act or process of introducing new ideas, devices, or methods*' (Alreshidi, Mourshed and Rezgui, 2017). As such, BIM in this study is considered as an innovation because it is a whole new approach to practise and advancing the profession which requires the implementation of new policies, contracts, and relationships amongst project stakeholders (Aranda-Mena *et al.*, 2009; Eastman *et al.*, 2011). To achieve this, a department is responsible for identifying an innovation and implementing it. In Company F, a business case is developed to justify the ROI and build-up the project plan to make sure that it is delivered correctly. This is then signed off and worked through delivery. This business case is developed through stakeholder engagement and scope definition.

After the process of planning, those benefits are tracked all the way through the lifecycle against the ROI and other project objectives. It is standard procedure that any investment coming through BIM in Company F will have a business case against it and business value will be tracked. These investments could be capital projects, technology systems and software systems or processes.

The whole process is documented through the management of KPIs. The information management team in Company F is responsible for tracking business value over a period of time and reporting of results on a consistent basis. They would specify how savings would be measured against a specific target or project. The realised savings will be compared with the expected results in the business case, that is, the forecasted ROI or business value.

The business value realisation process at Company F is a six-step process (Figure 7.5). The first is the gathering of benchmarking information for a period prior to the implementation of a particular system. Secondly, the business case will be developed to prove the business value of that system and how the organisation is aiming towards the full pay-off for an opportunity. The next step is to pilot the system for a period. During the pilot, data will be monitored consistently by the team. Fourthly, the results will be evaluated. The pilot results will be monitored and compared with the benchmarked data. In the event that the results are consistent with the benefits forecast, the system will be approved. If there is any variance in results, the team will have to look at the business case again to make adjustments. If the results are unsatisfactory, the proposal will be rejected. Finally, the approved system will be rolled-out organisation-wide. Even then, the system benefits will be consistently monitored, and business value reported.

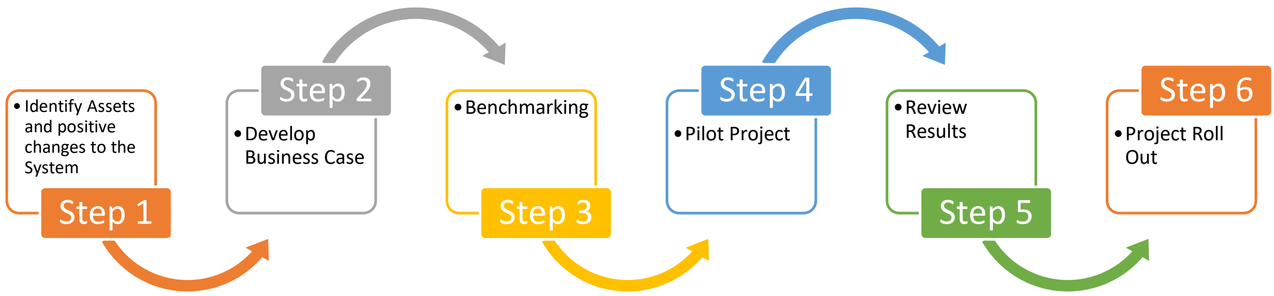


Figure 7.6: Company F Value Realisation Process

7.4.4.5 CHALLENGES OF BIM BUSINESS VALUE REALISATION IN COMPANY F

The following challenges have been identified in Company F, and they are; justifying dependency between systems and personnel; and difficulty in measuring BIM business value.

7.4.4.5.1 JUSTIFYING DEPENDENCY BETWEEN SYSTEMS AND PERSONNEL

One of the main processes of value realisation in Company F is developing the business case. This is where justifications of proposals are made. Company F understood that information contained in the systems were valuable, and they tried to hypothesise and justify dependencies between the systems and operational personnel. But in reality, most of the operational personnel and other specialists knew most of the information contained in those systems by heart, which they have acquired through many years of experience. Hence, the dependency on the systems was not as much as Company F wanted, and they experienced the difficulty of justifying theory against practice.

7.4.4.5.2 DIFFICULTY IN MEASURING BIM BUSINESS VALUE

Company F puts a lot of emphasis in trying to identify the value BIM brings to the entire system and how it can be realised. Therefore, a lot of effort is put in making the value stack up in terms of cost against benefits. Company F has found it difficult to isolate and appraise only the business value that BIM brings. This is because other organisational processes, personnel experience, systems and project variables also contribute to business value. The above assertions accord with existing literature (Barlish and Sullivan, 2012; Love *et al.*, 2013).

7.5 RESULTS: CROSS CASE ANALYSIS

The activity systems identified from the study data analyses (Section 7.5) are used for the cross-case analysis. Every activity system is evaluated and scored against the dimensions of BIM governance identified from the study literature review (Section 2.7). Furthermore, the maturity scales of the BAMM are used to grade each variable. They are:

- Tier 1: Ad-hoc (19-35): The overall characteristic of this level is that there are ad-hoc BIM-based processes within the organisation. Documentation is in variants of 3D, 2D electronic or paper-based formats with no specific requirements for information models;
- Tier 2: Defined (36-53): The general organisational trait of this tier is having un-coordinated building information models delivered at the end of the design and construction phases. Documentation may lack organisational-level standards for requirements and use within BIM-based AM processes;
- Tier 3: Managed (54-71): The common organisational attribute of this stage is the existence of semi-coordinated building information models. COBie-level information requirements are defined, and the delivery process is arbitrary;

- Tier 4: Integrated (72-89): The main organisational feature of this phase is the existence of fully integrated building information models with access to real-time data at the building or facility level. The BIM-based AM system operates with smooth interoperability and AM information is searchable for analysis.; and
- Tier 5: Optimised (90): The general organisational characteristic of this level is the management of activities at the multi-facility system level, including fully integrated systems combining general access with city-level information. The BIM-based AM system operates with smooth interoperability including the availability of asset information at the multi-facility or city level.

The numbers placed against the maturity scales are aggregate scores of the maturity appraisal.

Firstly, the summary of the within-case analysis is presented in Table 7.1. This summarises the organisational BIM business process capability of all four case studies in relation to the six activity systems. Secondly, the BIM business process capability is further evaluated and presented in Figure 7.6. Each company is appraised based on the maturity of the governance elements of each activity system. The activity systems are: BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management. The governance dimensions of people, process and technology, are appraised based on the following characteristics:

- **People**: Organisational strategy; BIM implementation strategy; collaboration; staffing; training; and business process capability of every activity system.
- **Process**: BIM standards; organisational BIM objectives; defined roles; effective use of data; supply chain integration; asset lifecycle integration; and value realisation management of every activity system.
- **Technology**: BIM systems; IT Systems; AM Systems; FM systems; organisational systems architecture; interoperability; data integrity; and data accessibility of every activity system.

Furthermore, the scoring for each governance element for each activity system is as follows:

- Ad-hoc – 1 Point
- Defined – 2 Points
- Managed – 3 Points

- Integrated – 4 Points
- Optimised – 5 Points

Therefore, data from the semi-structured interviews and archival analysis are used to score each activity systems and governance elements. The overall scores for each governance element are aggregated into a total figure. Figures 7.7 and 7.8 presents the evaluation of the four case studies. The total scores for each company are presented in Figure 7.7. Furthermore, Figure 7.8 presents a radar diagram showing the ratings for each of the activity systems and governance elements.

Table 7.1: Multi-case study assessment sheet

S/NO.	DESCRIPTION	COMPANY B	COMPANY C	COMPANY E	COMPANY F
1	SECTOR	Health	Education	Government-Mixed Use	Retail
2	BIM STRATEGY	Bilateral communication Software development (full strategy) Defining requirements (full strategy) Partnering with stakeholders (full strategy) Lifecycle approach (IPD)	Linked data Software development (full strategy) Development of information requirements (full strategy) Bottom-up	Asset digitalisation programme (full strategy) Defining requirements (full strategy)	Quality of information
3	CONTRACT MANAGEMENT	No established process for contract management	Contract database for contractors Ticket system	Tender to completion automation Invoicing automation Payment tracking	Invoicing automation Payment tracking
4	LIFECYCLE MANAGEMENT	Lifecycle planning of facilities through data Operational input to designs Lifecycle history of maintenance	Long-term planning of planned preventive maintenance	Lifecycle history of maintenance Lifecycle annual maintenance plans through data Space planning Wellbeing and productivity	Lifecycle history of maintenance Management of maintenance budgets Capital asset replacement
5	MAINTENANCE MANAGEMENT	Planned preventive maintenance Maintenance management of activities Tracking progress of work-orders	Planned preventive maintenance Better planning	Management of maintenance activities Indoor conditions management Workspace management IoT sensors automation Planned preventive maintenance	Planned preventive maintenance Management of maintenance activities Tracking progress of contractors IoT sensors automation
6	WORK-ORDER MANAGEMENT	Strategic reporting Work-order performance management CMMS Work-order portal Call centre	Strategic reporting Work-order performance management Ticket system	Strategic reporting Work-order performance management	Developing standard operating procedure document (full strategy) Call centre
7	VALUE REALISATION	Currently developing validation techniques Business case	No established value realisation process	Annual survey End-user satisfaction analysis	Business case tracking of business value (full strategy)
8	CHALLENGES	Workload in inputting operational data Managing data within asset models Developing measurable metrics for BIM value	Technology maturity Change management Translation of FM instances	Versions of BIM authoring software Lack of standards for operations and use phase Establishing as built models Lack of systems integration Utilising data points and quality of information	Justifying dependencies between systems and personnel Difficulty in measuring BIM value

S/NO	DESCRIPTION	COMPANY B					COMPANY C					COMPANY E					COMPANY F				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	BIM STRATEGY																				
	A. PEOPLE				X				X						X			X			
	B. PROCESS				X					X					X				X		
	C. TECHNOLOGY				X					X					X			X			
2	CONTRACT MANAGEMENT																				
	A. PEOPLE	X						X							X		X				
	B. PROCESS	X							X						X			X			
	C. TECHNOLOGY	X						X							X		X				
3	LIFECYCLE MANAGEMENT																				
	A. PEOPLE				X		X								X			X			
	B. PROCESS				X			X							X			X			
	C. TECHNOLOGY				X		X								X			X			
4	MAINTENANCE MANAGEMENT																				
	A. PEOPLE				X				X						X				X		
	B. PROCESS				X					X					X				X		
	C. TECHNOLOGY				X				X						X				X		
5	WORK-ORDER MANAGEMENT																				
	A. PEOPLE			X					X						X			X			
	B. PROCESS				X				X						X				X		
	C. TECHNOLOGY				X				X						X				X		
6	VALUE REALISATION MANAGEMENT																				
	A. PEOPLE		X				X							X						X	
	B. PROCESS		X				X						X							X	
	C. TECHNOLOGY		X				X						X							X	
	TOTAL SCORE	56					44					67					46				

Figure 7.7: Cross-case assessment sheet

The four case studies are assessed in Figure 7.7 with Companies B, C, E and F having an overall score of 56, 44, 67 and 46, respectively. This data is further presented in a radar diagram in Figure 7.8:

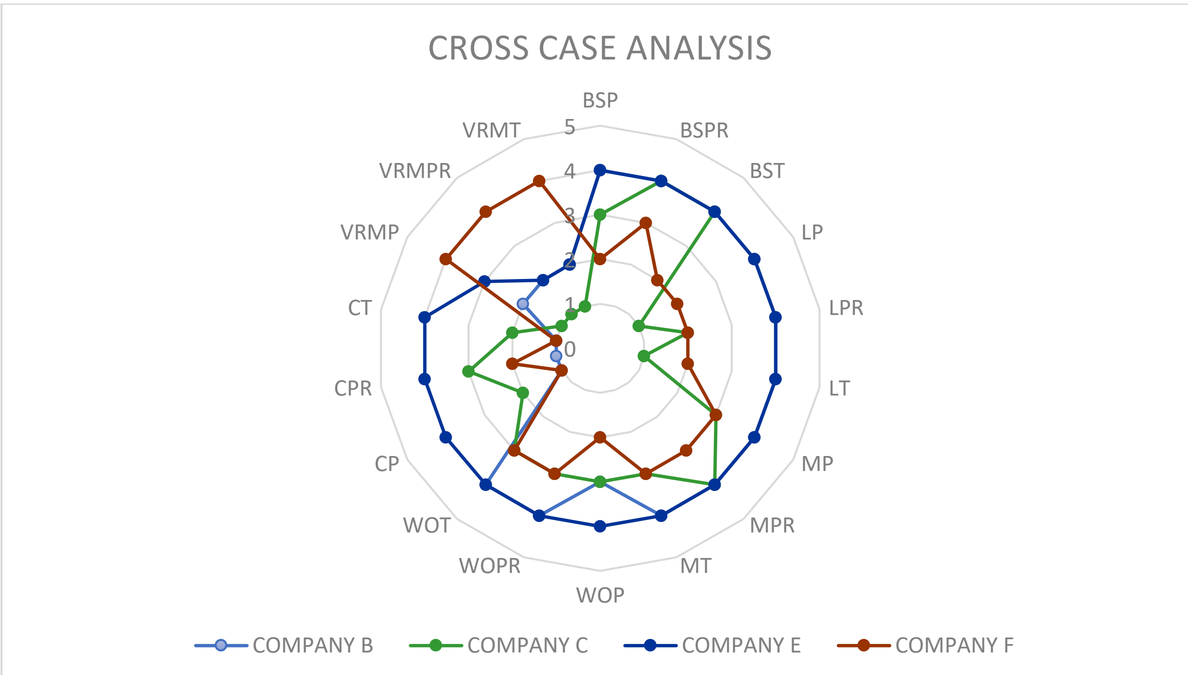


Figure 7.8: Radar diagram showing comparison of four case studies base on activity systems maturity

BSP-BIM Strategy People; BSPR-BIM Strategy Process; BST-BIM Strategy Technology; LP-Lifecycle Management People; LPR- Lifecycle Management Process; LT- Lifecycle Management Technology; MP-Maintenance Management People; MPR-Maintenance Management Process; MT- Maintenance Management Technology; WOP-Work-Order Management People; WOPR-Work-Order Management Process; WOT-Work-Order Management Technology; CP-Contract Management People; CPR- Contract Management Process; CT- Contract Management Technology; VRMP-Value Realisation Management People; VRMPR- Value Realisation Management Process; VRMT- Value Realisation Management Technology

The radar diagram (Figure 7.8) shows the comparison of the four cases in respect to the six activity systems, which are appraised from the perspective of people, process and technology. It can be seen that Company E has the highest overall maturity and that BIM value realisation management is the only weak activity system. The second highest overall is Company B, and the most robust activity systems are BIM strategy, lifecycle management and maintenance management. However, its weakest activity system is contract management. The third highest is Company F, with BIM value realisation management as its most effective activity system. However, its most underdeveloped activity system is contract management. The least matured overall is Company C having BIM strategy as the highest-rated activity system and the weakest being BIM value realisation management. All four cases are further evaluated according to each activity system in the following sections.

7.5.1 BIM STRATEGY

BIM strategy as an AM activity system involves the overall organisational policy in employing BIM in planning and directing asset operations and management. This aspect covers broad organisational BIM approaches; change management, performance management; stakeholder management; short-term and long-term organisational policy for utilising BIM-based business processes; and definition of specific organisational needs from BIM processes. The case studies are assessed and compared based on these criteria in Figure 7.9:

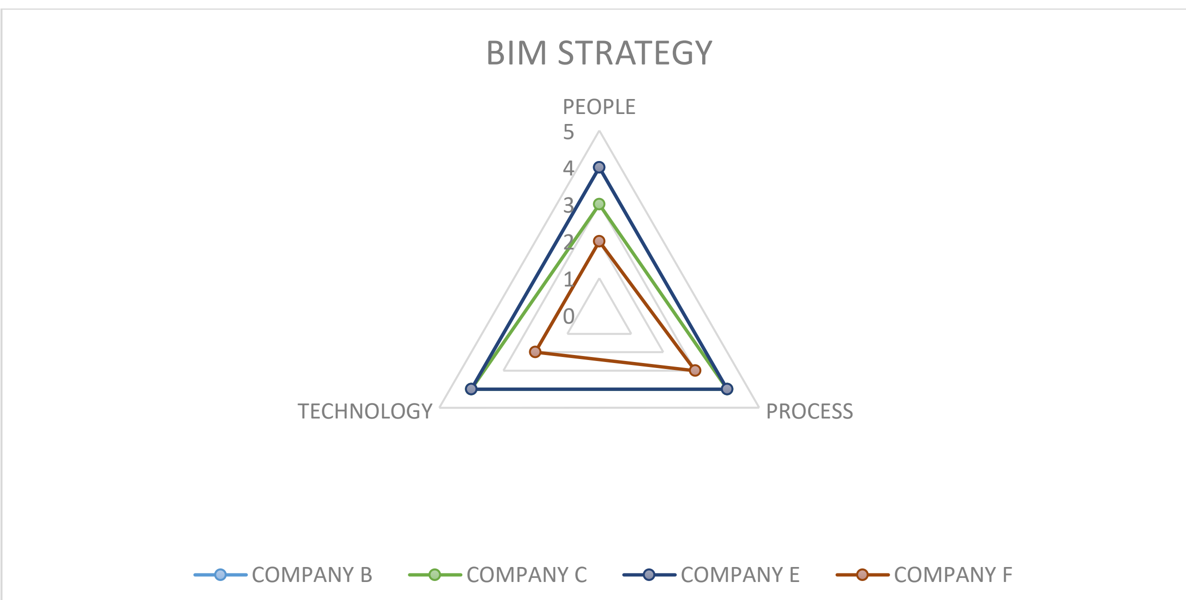


Figure 7.9: Cross-case analysis on BIM Strategy

This activity systems has the second-highest average across all four cases. The analysis in Figure 7.9 shows that Companies B and E have the most comprehensive organisational BIM strategy, and Company F has the least comprehensive BIM Strategy. However, Company C has a matured BIM strategy rating with only its people dimension a point lower than Companies B and E. This is as a result of the bottom-up approach in Company C.

7.5.2 CONTRACT MANAGEMENT

The AM activity system of contract management involves organisational oversight and implementation of BIM-based processes in the creation, negotiation, analysis, performance monitoring, risk management and full execution of contractual obligations while minimising risk and maximising financial and operational performance. This aspect involves; performance monitoring; invoice tracking; checking compliance; and tendering. The case studies are assessed and compared based on these criteria in Figure7.10:

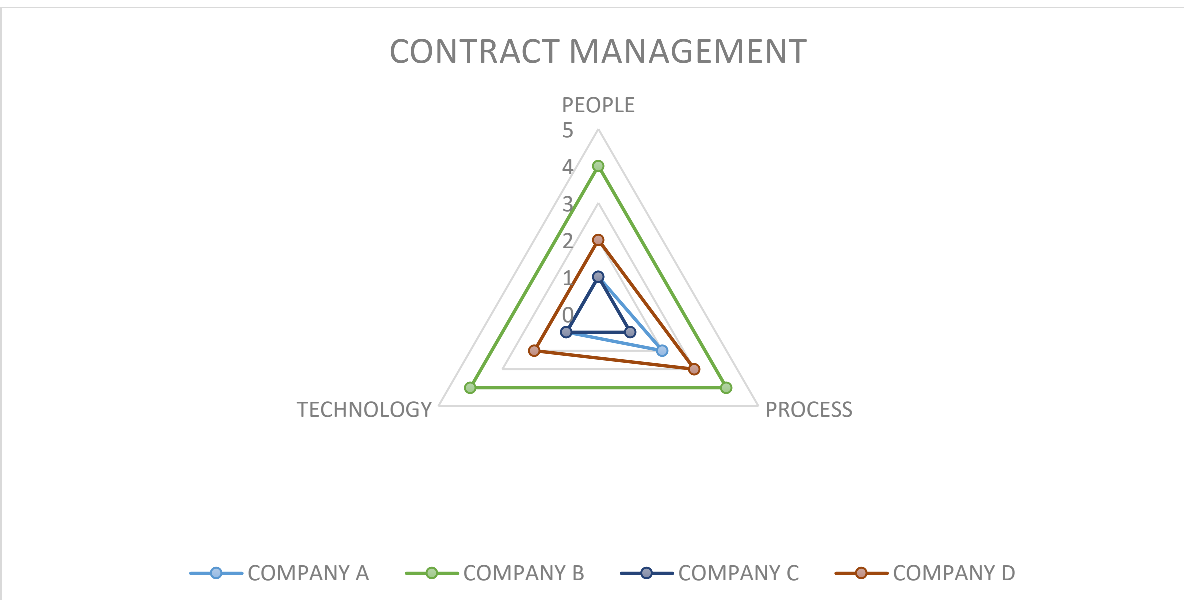


Figure 7.10: Cross-case comparison on Contract Management

This is the least developed activity system across all four cases. The analysis in Figure 7.10 shows that overall Company E has the most methodical approach towards contracts management. The second and third highest are Companies C and F, respectively. Company B is the lowest and compared to Company F, and Company B is less mature in the process dimension. This is because there are currently no established organisational procedures for contracts management in Company B.

7.5.3 LIFECYCLE MANAGEMENT

Lifecycle management is an activity system which involves the organisational use of BIM in all successive stages involved in asset development, that is, from inception to disposal. This aspect involves the holistic approach to organisational BIM standards covering asset development stages; data integration across asset development phases; data integration; process standardisation; technological capability; and human inclusion. The case studies are assessed and compared based on these criteria in Figure 7.11:

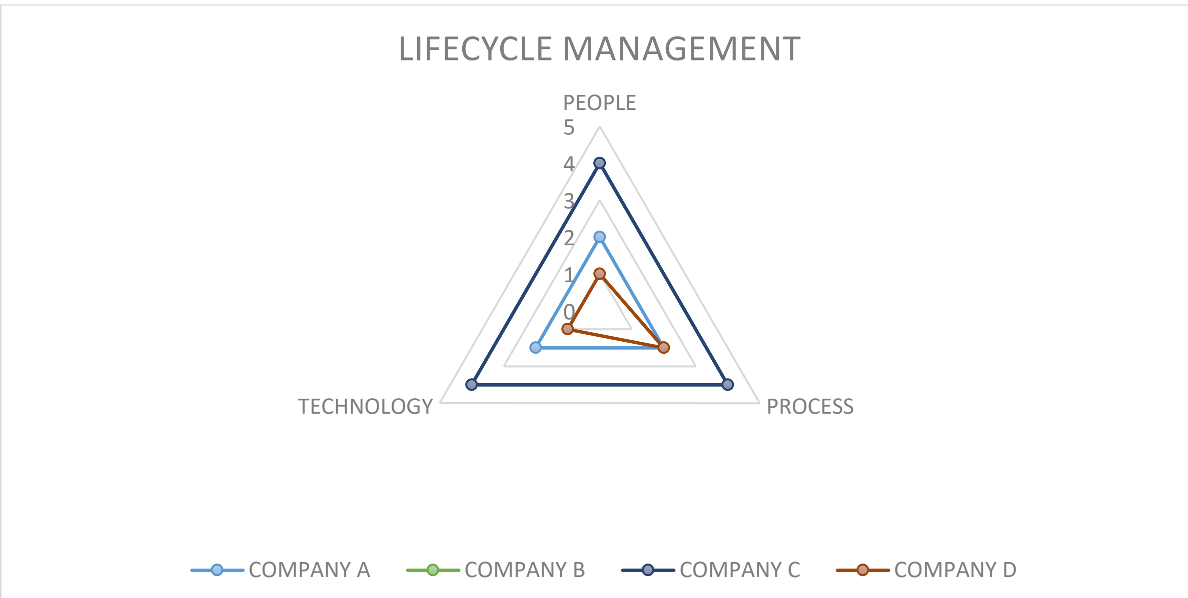


Figure 7.11: Cross-case comparison on Lifecycle Management

The analysis in Figure 7.11 shows that Companies B and E have the most sustainable approach in lifecycle management, and Company C has the least defined approach. Compared to Company C, Company F has a higher maturity in its people and technology dimensions.

7.5.4 MAINTENANCE MANAGEMENT

The activity system of maintenance management is centred around the effective management of resources and systems with the aim of checking compliance, controlling costs and optimising efficiency using BIM-based processes. This involves the organisational culture of utilising BIM in reactive, preventive, predictive, proactive and passive based maintenance practices. The case studies are assessed and compared based on these criteria in Figure 7.12:

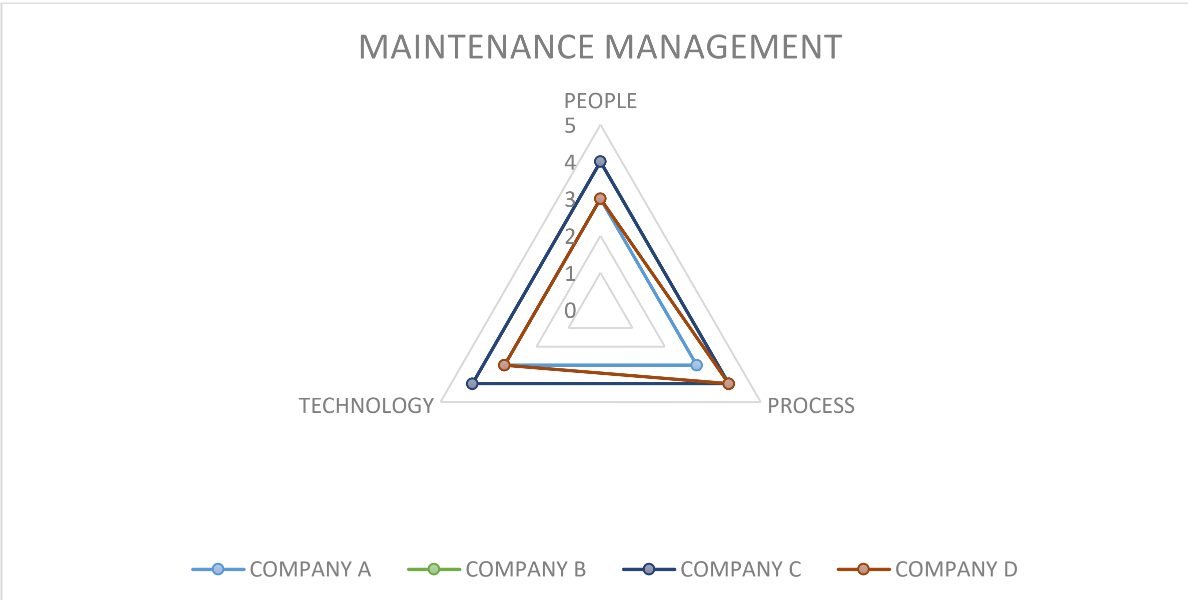


Figure 7.12: Cross-case case comparison on Maintenance Management

This is the most developed activity system across all four cases. The analysis in Figure 7.12 shows that Companies B and E have the most accomplished BIM-based maintenance management practices. Compared to Company F, Company C has a higher maturity in the process dimension. Company F is considerably proficient but has the least overall maturity in maintenance management.

7.5.5 WORK-ORDER MANAGEMENT

Work-order management as an AM activity system involves the comprehensive organisational approach towards utilising BIM-based processes in creating, scheduling, updating, budgeting, analysing, prioritising and tracking of work-orders. This aspect involves; organisational task management protocols; process standardisation and workflows; identification of user characteristics; definition of individual and organisational data needs; automated cost estimates and invoicing; and supply chain integration. The case studies are assessed and compared based on these criteria in Figure 8.13:

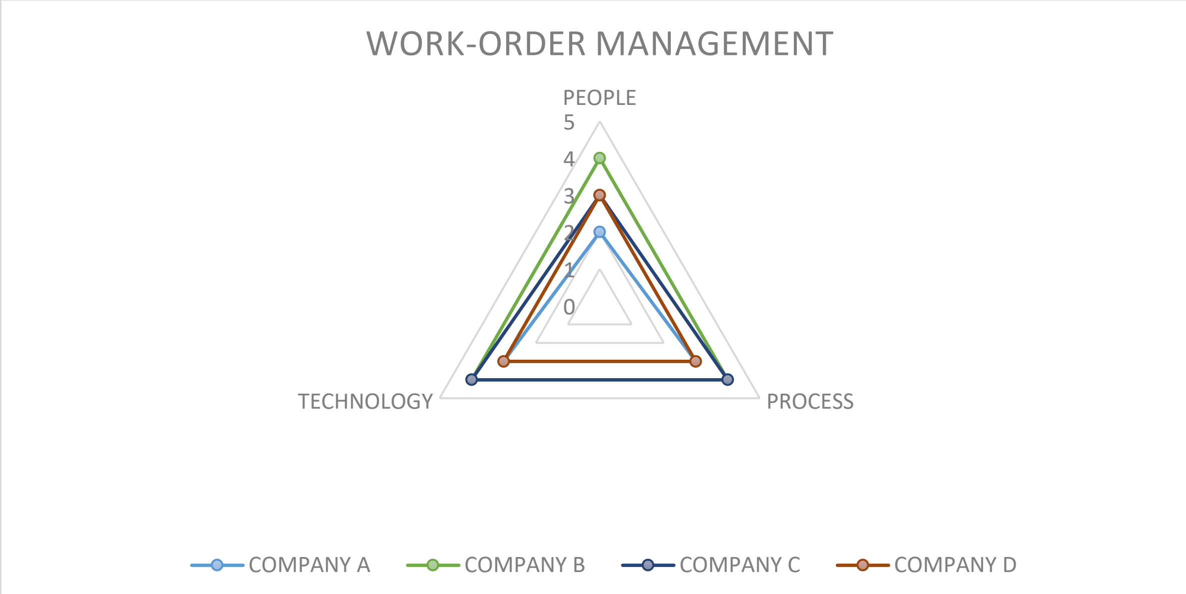


Figure 7.13: Cross-case comparisons on Work-order Management

This activity system has the third-highest average across all four cases. The analysis in Figure 7.13 shows that overall Company E has the most systematic approach towards work-order management. Companies B and C are rated second and third, respectively. Compared to Company E, Company B has a lower maturity in the people dimension. Furthermore, compared to Company C, Company F has a lower maturity in the people dimension.

7.5.6 VALUE REALISATION MANAGEMENT

Value realisation management as an AM activity system that involves the establishment of organisational processes for the definition, planning, identification, monitoring and realisation of BIM business value within the organisation and across different stages of the lifecycle. This aspect involves; formulation of organisational performance targets; establishment of value measurement techniques; definition and monitoring of KPIs; change management strategies; and stakeholder management strategies. The case studies are assessed and compared based on these criteria in Figure 7.14:

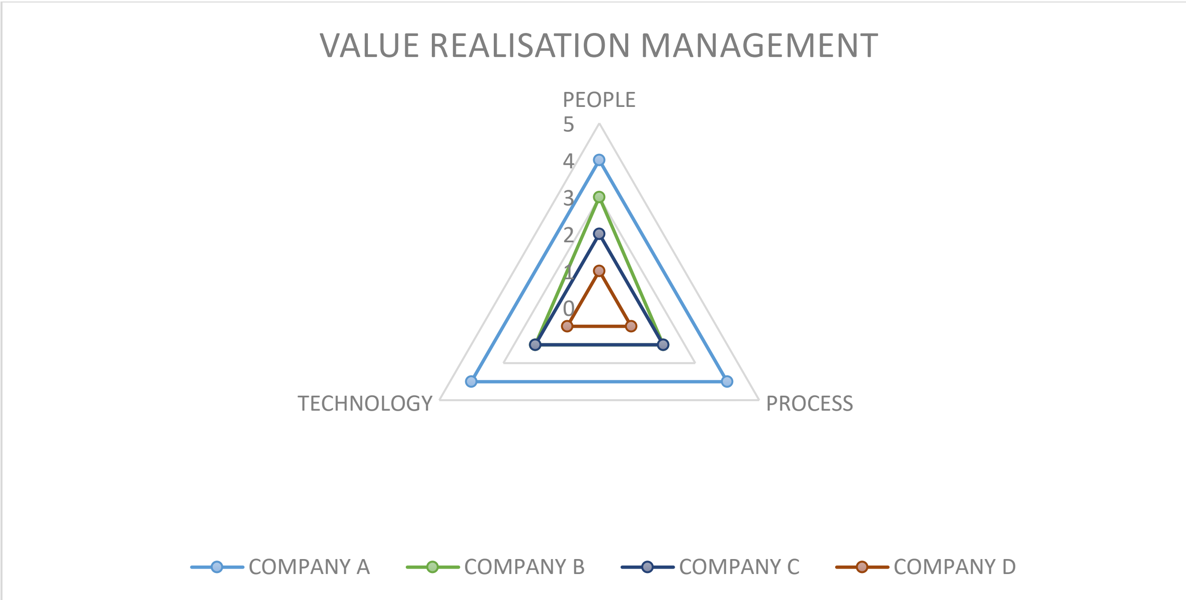


Figure 7.14: Cross-case comparison on Value Realisation Management

This activity system has the second least average across all four cases. The analysis in Figure 7.14 shows that overall Company F has the most organised approach towards value realisation management. Companies E and B are the second and third highest, respectively. Compared to Company B, Company E has a more mature people dimension. Company C has the least overall maturity because there are currently no established organisational procedures for value realisation management within the organisation.

7.5.7 CROSS-CASE ANALYSIS SUMMARY

From the cross-case analysis, the following findings have been deduced:

- Overall, Company E is the most proficient and Company C is the least developed.
- The analysed case studies focus more on the activity system of maintenance management in implementing BIM in asset operations.
- BIM strategy is the second most focused area for BIM implementation in asset operations.
- Contract management is the least focused activity system in BIM implementation in asset operations.
- Value realisation management is the second least developed area in BIM implementation in asset operations.

- The process dimension is the most developed BIM governance dimension in asset operation across all four cases.
- The people dimension is the least developed BIM governance dimension in asset operation across all four cases.
- There is no evidence that the asset owners' business sector influences the organisational value realisation approaches across all four cases

Finally, all four cases have been appraised and are presented in the BAMM (Figure 7.15) in relation to the results of the cross-case assessment sheet (Figure 7.7):

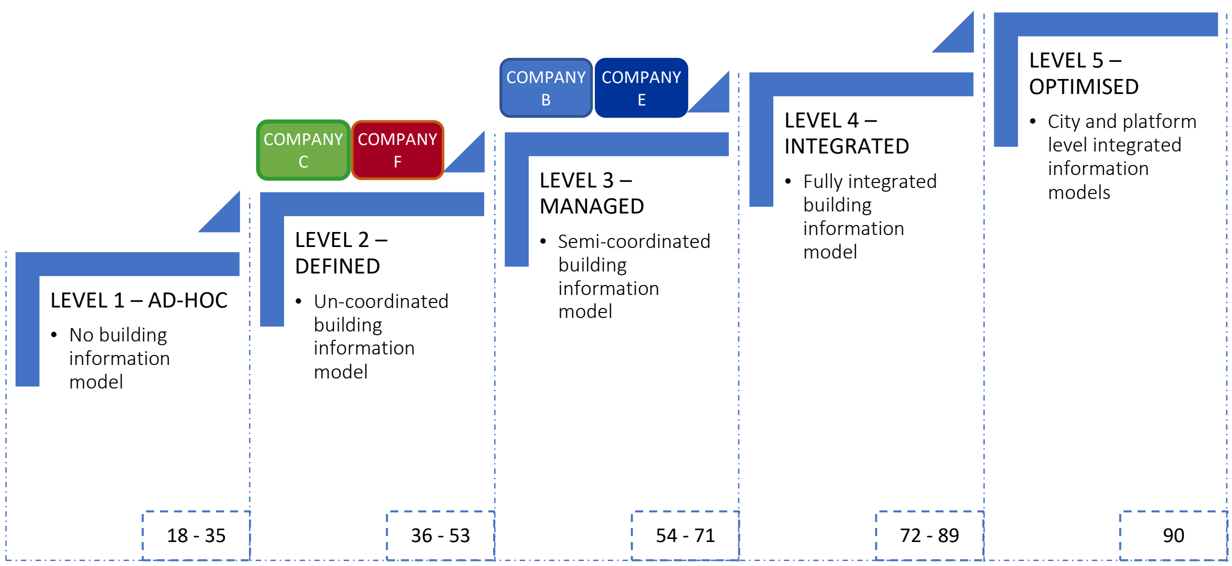


Figure 7.15: Maturity matrix for cross-case analysis

7.6 CONCLUSION

The aim of the study is to identify the vital AM tasks that drive BIM business value for an asset owner. This study identifies six AM activity systems that drive business value for an asset owner. The six main activity systems cover a wide aspect of AM business processes during asset operations. The study notes that these business processes are critical to the asset owner when realising BIM business value in asset operations. The ability to realise value from BIM-based processes depends on the determination of the asset owner to continuously develop and improve all aspects of the activity systems from the organisational dimensions of people, process and technology.

The findings in this study lead to four main conclusions. First, the study identifies BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management as key activities that drive BIM business value for an asset owner. Second, business value can be derived by the asset owner if the six activity systems are effectively executed and continuously improved to an advanced stage of maturity. Third, the study does not find any evidence of the asset owners' business sector influencing organisational value realisation approaches across all four cases. Fourth, the study identifies barriers to identifying BIM business value realisation in asset operations. The elimination of these factors will play a role in the realisation of BIM business value by the asset owner. Finally, in terms of developing the BIMAsset VRM, the findings in this chapter have indicated that the BIM governance dimensions of people, process and technology impact BIM implementation and subsequent value realisation. The findings underscore the significance of incorporating an element in the BIMAsset VRM that covers people, process and technology.

7.7 CHAPTER SUMMARY

This chapter focuses on the knowledge gap of identifying key AM business processes that drive BIM business value. The study investigates the AM business processes of four asset owners that implement BIM in asset operations. The study is exploratory and descriptive in nature. The study adopts a qualitative multi-case study strategy. Furthermore, the study involves a three-stage research design using interviews and document analysis to facilitate a cross-case analysis from the perspective of activity systems and the dimensions of BIM governance. The study identifies six key activity systems that drive BIM business value for an asset owner, which are; BIM Strategy, Contract Management, Lifecycle Management, Maintenance Management, Work-order Management and Value Realisation Management. Furthermore, the study highlights that BIM business value can be realised by the asset owner if the six activity systems are effectively executed and continuously improved to an advanced stage of maturity. Finally, the study identifies barriers to identifying BIM business value realisation management in asset operations. These factors play a role in the realisation of BIM business value in the operations and use phase. Finally, the findings in this chapter underscore the significance of incorporating an element in the BIMAsset VRM that covers people, process and technology.

CHAPTER 8

BIMASSET VALUE REALISATION MODEL

UNIVERSITY OF LIVERPOOL

8.0 BIMASSET VALUE REALISATION MODEL

8.1 CHAPTER INTRODUCTION

This chapter provides the final studies in relation to Research Objective 6: To investigate the techniques and strategies of measuring the business value of BIM in AM processes and how intangible value can be measured; and Research Objective 7: To develop a model for business value realisation of BIM implementation in the lifecycle management of assets for clients. The first seeks to address one of the research gaps identified in Chapter 2. That is, the lack of understanding on approaches, tools and techniques for evaluating BIM business value during asset operations. Asset managers lack socio-technical approaches to enable them to track BIM business value during asset operations. This may be due to the complex role and scope of BIM implementation, thereby making business value realisation a complicated process. Also, asset managers lack techniques for conceptualising intangible value. In order to address the research problem, secondary data through a literature review was used to explore areas related to value identification, measurement and realisation for tangible and intangible BIM business value. The rationale here is that for there to be any business value in BIM-based AM processes; the asset owner needs to understand how to manage and evaluate BIM business value in AM. The importance of this chapter with respect to the development of the BIMAsset VRM is that it provides a better understanding of the justification that was made by the researcher for the identified elements and sub-elements in relation to BIM business value realisation.

The second seeks to bring together all the findings in the results chapters in the form of a model development that will guide the asset owner in realising BIM business value in the operations and use phase. It addresses the overall research problem by providing The BIMAsset Value Realisation Model to address the BIM business value realisation in AM. The importance of this chapter with respect to the development of the BIMAsset VRM is that it brings together all the identified elements and sub-elements into one single model. The justifications for the BIMAsset VRM elements and sub-elements are discussed and theoretically validated in Chapter 9.

8.2 RESEARCH JUSTIFICATION

The main purpose of this chapter is to present the outcome of the thesis by developing the BIMAsset Value Realisation Model (BIMAsset VRM). This chapter brings together all the elements identified the results chapters into one single whole. This chapter is presented as a full study in its own right. Therefore, background literature is reviewed, detailed methodology outlined, and the BIMAsset VRM is presented.

The motivation for this study is as a result of the lacklustre adoption of BIM in the operations and use stage, particularly in AM. BIM in AM is an area that has not been given much attention by researchers. This research seeks to address a knowledge gap around value realisation of BIM in AM by adding more prospects in the establishment of the business value of BIM in the lifecycle of built assets. This is imperative because the asset owner stands to gain the most from BIM implementation amongst all stakeholders in the AEC industry (Parsanezhad and Dimyadi, 2014). Some asset owners find themselves adopting BIM but cannot find sufficient economic justification. However, the main issue is in adopting a comprehensive approach for attaining the business value. This can be related to weaknesses in measurement techniques and business value realisation practices of the AEC industry (Irani, 2010; Love *et al.*, 2013). These factors make it difficult to evaluate the business value of IT-based tools or methodologies such as BIM (Vass and Karrbom Gustavsson, 2014b). Therefore, there is a need for further research in developing the understanding of the asset owner on the economic value that BIM enables and how value can be realised (Vass and Karrbom Gustavsson, 2014b). As such, the notion of value in this research is economic. That is a service or outcome that is of economic benefit to an asset owner (Weigand *et al.*, 2006). Value in this study may be tangible or intangible. Furthermore, a number of studies have attempted to measure the business value of BIM (Giel, Issa and Olbina, 2010; Kreider, Messner and Dubler, 2010; Barlish and Sullivan, 2012; McGraw-Hill, 2012; Love *et al.*, 2013; Love *et al.*, 2014; Walasek and Barszcz, 2017), but more research is needed to clarify the difficulty in measurement of BIM business value in the operations and use phase.

Furthermore, few studies have discussed the value of the BIMAsset in the AEC industry (Patrick *et al.*, 2012; Halmetoja, 2019). As such, this study aims to enhance the proficiency of asset managers to derive BIM business value from their built assets through the utilisation of a BIMAsset VRM. The study develops a model which focuses on how BIM derives value and its applicability to AM business processes. In this chapter, the model is presented, its constituent parts explained, and the procedures reviewed.

8.3 CHAPTER 8 – DETAILED METHODOLOGICAL APPROACH

This study seeks to provide a model that will aid asset managers in evaluating the business value of BIM implementation in an AM system in the lifecycle of assets. The study also aims to provide a theoretical basis for focused studies in relation to BIM business value realisation in AM. The study will address the following research questions:

- How can the BIMAsset Value Realisation Model support asset managers in deriving BIM business value?
- How can an asset manager appraise organisational maturity in relation to BIM business value realisation during asset operations?
- What are the techniques and strategies of measuring the business value of BIM in AM processes, and how can intangible value be linked to tangible value?

8.3.1 RESEARCH METHODS

The study is conducted to understand the phenomenon of lack of BIM business value realisation in AM and to develop a framework that will address the shortfalls of that phenomenon. Considering that BIM is an IT/IS based technology and its implementation has social and cultural implications. This study adopts a socio-technical perspective to addressing the research problem. The study aims to investigate the interaction between the asset owner and BIM in an AM system and how value can be realised. It is assumed that the appropriate implementation of BIM by an asset owner would enable effective execution of AM tasks, which in turn ensures the achievement business objectives. Furthermore, the study adopts an abductive and qualitative approach in order to closely understand the phenomenon of BIM business value realisation in AM. The abductive method involves the process of combining deduction and induction in a back and forth manner in collecting data and analysing it to in order to develop the BIMAsset VRM (Saunders, Lewis and Thornhill, 2016). This encompasses Research Objectives 1, 2, 3 and 4 (deductive) and Research Objective 5 (inductive).

The research was based on five studies of BIM business value realisation, which were conducted over a three-year period. Data is collected through interviews and document analysis. The documents analysed include corporate strategy documents such as BIM objectives, standards, protocols and policies. Semi-structured interviews are used to explore stakeholders' perspective and interpretations of the relationship on BIM in AM and how value is generated and measured. A total of sixteen interviews involving thirteen participants are conducted to represent a number of stakeholders, namely; Health, Retail, Education, Government mix-use and Consultants' perspectives in AM. The literature review and outcomes of the case study exercise fed into the initial BIMAsset VRM. The framework is consistently revised and refined in eight versions in order to capture the phenomenon effectively (Appendix D). Rightfully in qualitative studies, a theory or framework can be presented as the final outcome of a study (Creswell, 2003).

To ensure validity of the study, a focus group in the form of a six-member expert panel is conducted to validate the BIMAsset VRM and BIMAsset Maturity Model (BAMM) tool presented in this study based on: fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency (Proctor and Capaldi, 2006). The results of the focus group show that there is a majority opinion that the BIMAsset VRM satisfies the above validation criteria. Furthermore, in the data analysis shows there is a majority in the opinion that the BAMM satisfies the above validation criteria. Furthermore, participant validation is conducted by sending transcripts and analysed data for accuracy authentication (Saunders, Lewis and Thornhill, 2016). Also, data validity is ensured by using multiple sources of data in the study (Patton, 2002). Section 8.4 is a systematic compilation of the study findings.

8.3.2 RESEARCH PROCESS: INDUCTIVE REASONING SRQ-5

This section presents the methodological process of this part of the study. Here, inductive reasoning is adopted in SRQ-5 to develop a framework for linking intangible to tangible value. This aspect of the abductive process of the PRQ involves inference to the best explanation by developing a novel approach for measuring intangible value through business value linkage. The research progression is shown in Figure 8.1:

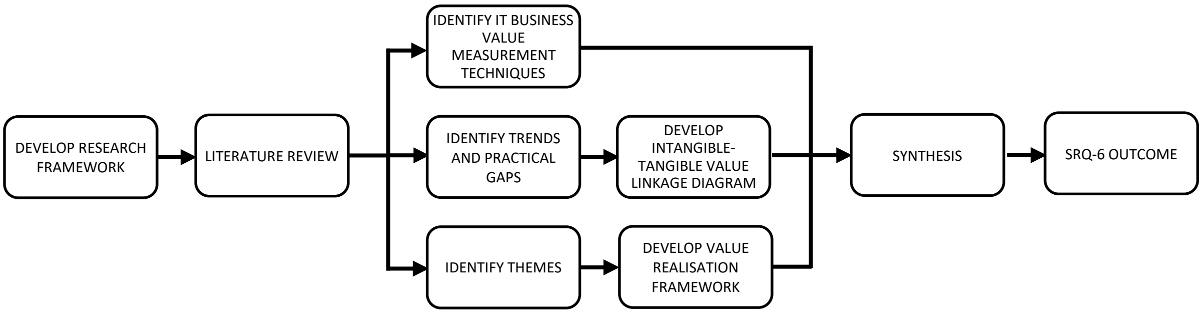


Figure 8.1: Inductive reasoning SRQ-5

8.3.3 RESEARCH PROCESS: ABDUCTIVE REASONING PRQ

This section presents the methodological process for the whole study. The systematic answering of the PRQ required inductive and deductive activities. Deductive reasoning is adopted in understanding the phenomena of BIM business value in five studies. Inductive reasoning is adopted in appraising theoretical developments in the AEC industry and developing frameworks that will guide asset managers to realise BIM business value. This is expressed in Figure 8.2:

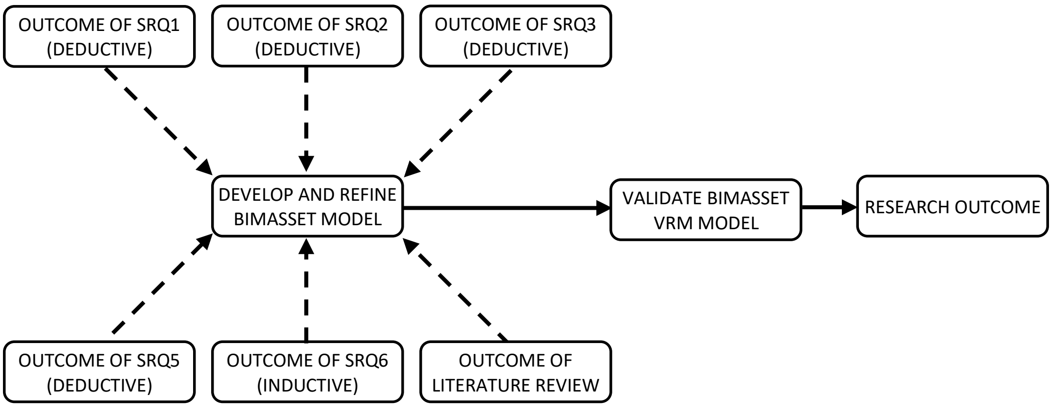


Figure 8.2: Abductive reasoning PRQ

8.4 BIMASSET VALUE REALISATION MODEL

8.4.1 THE MODEL

The BIMAsset VRM presented in this section is the synthesis of the literature review and study primary data. This is a conceptual model consisting of six constituent elements. They are Influencers, Input, Output, Drivers (tangible and intangible value), Core and Business Value Realisation Dimension (Figure 8.3).

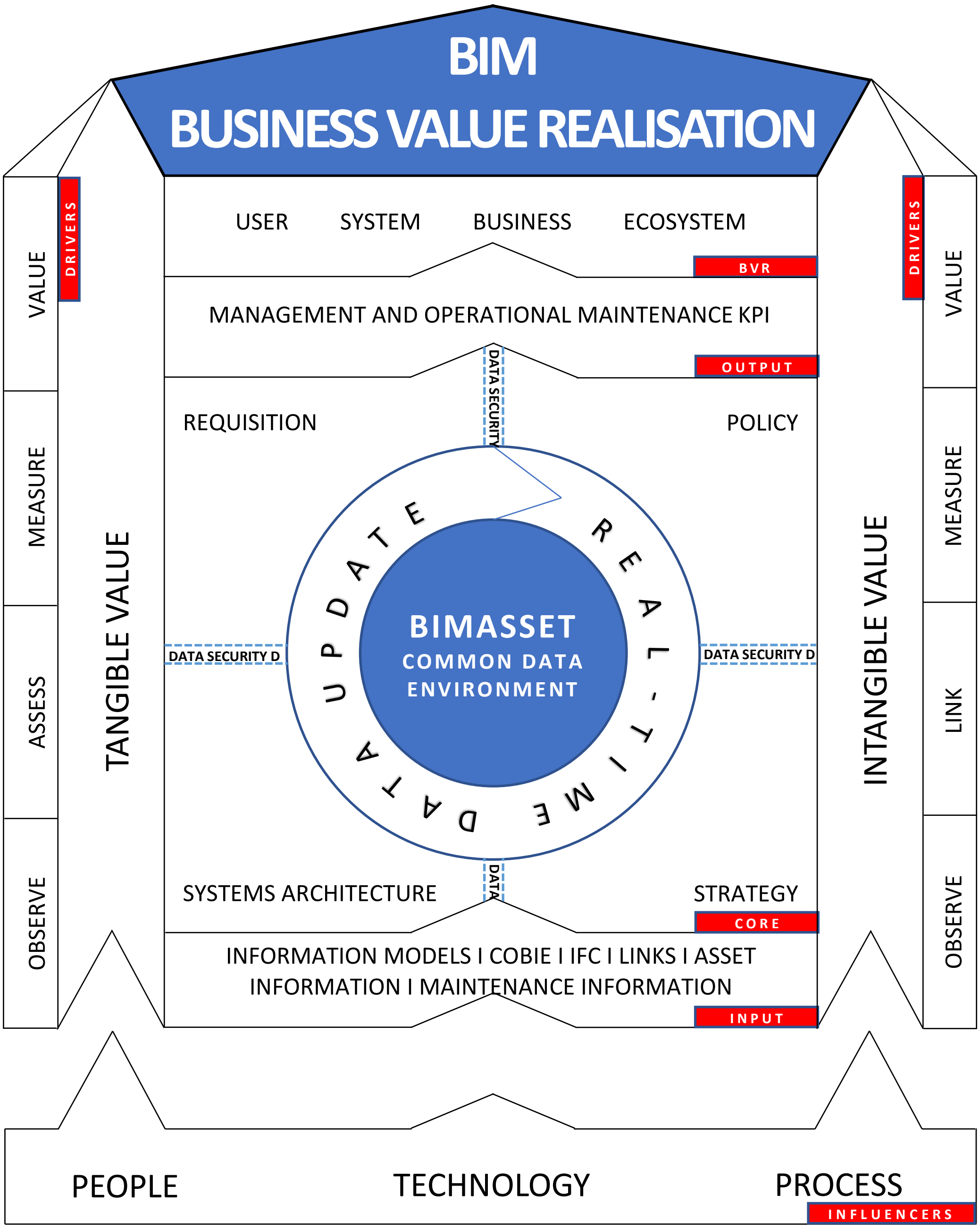


Figure 8.3: BIMAsset Value Realisation Model (BIMAsset VRM)

8.4.1.1 INFLUENCERS

This element of the model comprises the basic actors of the entire system. People, process and technology, are widely recognised BIM governance dimensions in the business process execution and subsequent value delivery of organisations (Leavitt, 1964; Bosch, Volker and Koutamanis, 2015; Prodan, Prodan and Purcarea, 2015; Alreshidi, Mourshed and Rezgui, 2017). Thus, people denote the stakeholders; process represents the standards, policy and protocols; and technology refers to automation mediums, tools and techniques within the organisation. These governance dimensions are involved in processing inputs, performing tasks, managing outputs and driving value for the asset owner through the BIMAsset VRM.

8.4.1.1.1 PEOPLE

People in the context of this model represent the human aspect that is central to any organisational activity. They are in charge of decision-making, planning, implementing, using of the data and realising the value in any AM system (Brous *et al.*, 2014). Furthermore, people provide the leadership and control required to perform any business activity. The participants involved in BIM value realisation include stakeholders at the strategic, operational and tactical levels within the owner-operator organisation. An asset owner will have to develop, align and implement business strategies that will effectively engage stakeholders within this BIM governance dimension in value realisation management activities in a BIM-based AM system. Accordingly, effective strategies for achieving this have been presented in Chapter 5 of this thesis.

8.4.1.1.2 PROCESS

Process represents the organisational conventions that govern the entire business activities of an organisation ranging from investment strategies to everyday business activities. In this context, Process refers to organisational practices which calibrate the entire system from the Input stage to the Business Value Realisation (BVR) stage, where value is realised. This BIM governance dimension provides the standards, policy and protocols to deliver value in an owner-operator organisation. In order to realise BIM business value, organisational processes have to be standardised, including the deployment of best practices with simplified reporting techniques. Accordingly, these strategies have been demonstrated in Chapter 6 of this study.

Asset coding and hierarchy techniques must be structured and reviewed in order to enable efficient task management and execution. Furthermore, the business case and a BIM value realisation plan are critical business processes for the asset owner in order to realise value. Subsequently, these strategies have been highlighted in Chapter 5 of this thesis.

8.4.1.1.3 TECHNOLOGY

Technology refers to the organisation's physical infrastructure that provides a medium for efficient and effective data management in the form of virtual environments. This is what manages all connected data sources within the BIM-based AM system that exist in an owner-operator organisation (Brous *et al.*, 2014). Technology, as a BIM governance dimension, supports the entire data management process and comprise of the different AM, FM and BIM systems deployed within the organisation. This information can be from single or multiple sources which should be easily retrievable within the system. Information filters need to be created within systems so that asset information can be accessed using asset codes, property numbers and other searchable parameters. Asset managers should ensure that there is smooth interoperability between systems.

8.4.1.2 CORE

This element is where the actual business process transformation takes place. The core is divided into four constituent parts, namely: requisition, policy, strategy and systems architecture. It also includes guidance aspects such as real-time data update and data security. These aspects are discussed in the following sections:

8.4.1.2.1 REQUISITION

This aspect of the core involves the specific adapted organisational requirements for AM tasks. These are the standard informational requirements for the asset owner from the design and construction phases. Alternatively, for existing built assets, these could represent the standard requirements for established organisational protocols. This aspect of the core is critical to the value realisation process because the asset owner is only able to realise value when organisational information needs have been defined, and expected outcomes have been established. These informational sets include, but are not limited to: Organisation Information

Requirements (OIR); Asset Information Requirements (AIR); Employer Information Requirements (EIR); Asset Information Model (AIM); Project Information Model (PIM); Master Information Delivery Plan (MIDP); Task Information Delivery Plan (TIDP); Level of Detail/Development (LOD); and Level of Information (LOI) (Figure 8.4). Accordingly, aspects related to how asset owners can address the informational requirements have been demonstrated in Chapter 4 of this thesis.

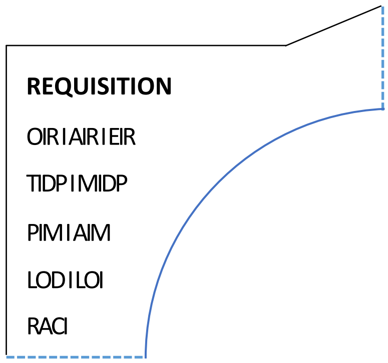


Figure 8.4: Requisition

8.4.1.2.2 POLICY

Policy refers to the organisational, regulatory and industry standards that determine how data governance should be conducted during AM tasks. These are standards that define how information should be produced, exchanged, stored, processed and regulated within owner-operator organisations. By utilising such standards, organisations are able to attach values to data sources and data content, thereby, treating data as an object of policy through regulating the processes of data management (Dawes, 2010). This aspect of the core involves the BIM policy documents which the organisation deals with daily. These could be protocols mandated by the government or industry standards. The document sets include, but are not limed to: British Standards Institute (BSI) standards on BIM (BSI, 2008a; BSI, 2013; BSI, 2014a; BSI, 2015); National Building Specification (NBS) standards (NIBS, 2007); Construction Industry Council (CIC) BIM Protocol (CIC, 2013); and Government Soft Landings (GSL) (Figure 8.5) (Cabinet Office, 2012). Similarly, Kassem, Succar and Dawood (2013) report a number of noteworthy BIM industry documents that combine protocols, requirements and guidelines related to BIM workflows and deliverables.

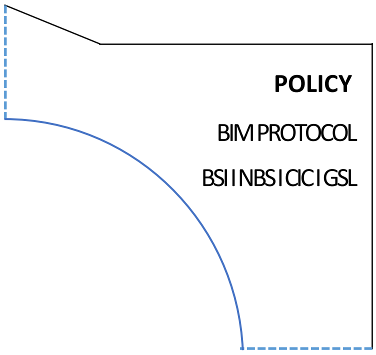


Figure 8.5: Policy

8.4.1.2.3 STRATEGY

Strategy in this context represents the designated plan of action for BIM implementation and subsequent value realisation within an owner-operator organisation. This aspect of the core is what determines key actions in relation to data governance, which are defined by the governance domains, decision domains and locus of accountability for decision-making (Khatri and Brown, 2010). These strategic sets include, but are not limited to: Project Implementation Plan (PIP); BIM Implementation Plan (BIM IP); BIM Execution Plan (BEP); BIM Value Realisation Plan (BIM VRP); and continuous improvement (Figure 8.6). Accordingly, aspects related to how asset owners can address the activities of BIM strategic implementation and value realisation in AM have been demonstrated in Chapter 5 of this thesis.

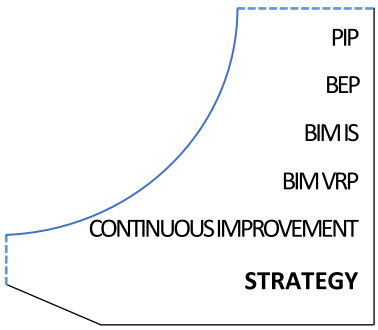


Figure 8.6: Strategy

8.4.1.2.4 SYSTEMS ARCHITECTURE

Systems architecture is recognised as one of the important components in achieving the business value of BIM investments (Gartner, 2003). This part of the core involves the basic system's structure of the owner-operator organisation. That is the scalability of the operating systems and databases, including the level of integration of the networks for performing AM tasks. These systemic sets include, but are not limed to: AM Systems, BIM systems, BMS systems, and FM systems (such as CAFM, CMMS and IWMS) (Figure 8.7). Accordingly, aspects related to how asset owners can address the planning and establishment of organisational systems architecture have been covered in Chapter 5 of this thesis.

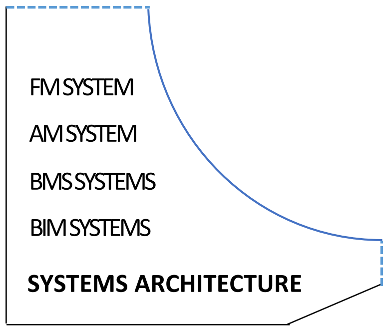


Figure 8.7: Systems Architecture

8.4.1.2.5 REAL-TIME UPDATE, DATA SECURITY AND BIMASSET CDE

The model requires the provision of real-time data with full systems integration within a BIM-based CDE. Furthermore, as a guide, PAS 1992-5 (BSI, 2015) provides specifications for data security relating to BIM-based processes.

8.4.1.3 INPUT AND OUTPUT

This element of the model comprises the inputs and outputs of the system involving the raw or refined information fed into the BIM-based AM system and the output generated. However, the study adopts the perspective of Munir *et al.* (2019) in describing the components of a BIM-based AM system. The rationale for this is that it sufficiently covers conceptual BIM-based activities that are involved in producing outputs that can be utilised by the asset manager to perform AM tasks. Figure 8.8 represents the conceptual flowchart of input, task and output. This view is adopted and improved upon in developing the BIMAsset VRM flowchart in this study.

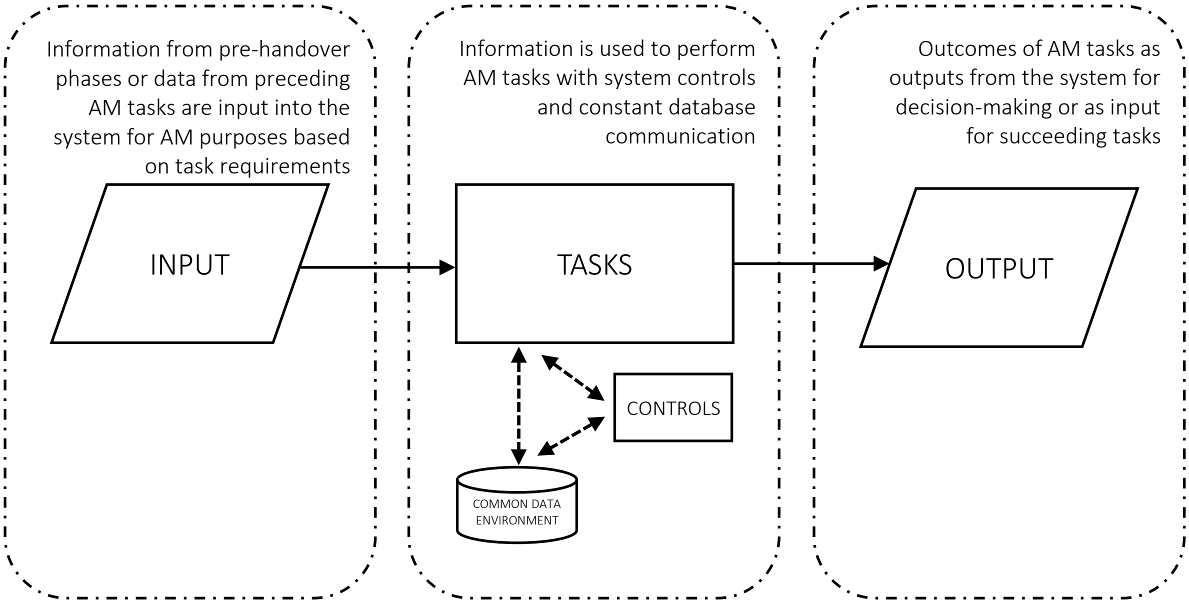


Figure 8.8: Input-Output of a BIM-based AM System (Munir *et al.*, 2019)

8.4.1.3.1 INPUT

The input to this system includes, but is not limited to: all building information models, asset information models, project information models, associated links, COBie, asset information and maintenance information. Input in this context refers to data as output from design and construction processes or data created within AM tasks for use in other AM activities. Here, the relevant information will be extracted for execution of AM tasks. Aspects related to input have been addressed in Chapter 5 of this thesis.

8.4.1.3.2 OUTPUT

The outputs of the system are those from the AM tasks, which will be utilised by the owner-operator organisation. These are the management and operational maintenance KPIs which include, but are not limed to: physical asset parameters, maintenance schedules, asset lifecycle data, resource allocation data, supply chain data and task management data. The system is expected to have the capability of collecting and interpreting accurate real-time data regarding asset condition, asset valuation, asset capacity, and performance. These outcomes can be used for decision-making and as inputs for subsequent AM tasks. The output in the form of outcomes are to be used by the asset manager to be able to establish the actual value that BIM brings to the organisation. Accordingly, aspects related to how asset owners can monitor outcomes and track BIM business value within the organisation have been addressed in Chapter 5 of this thesis.

8.4.1.4 DRIVERS – TANGIBLE AND INTANGIBLE VALUE

This element of the model comprises the value drivers meaning the dimension relating to the tools and techniques for measuring BIM business value. Measuring BIM business value can be a daunting task because not all benefits can be easily tracked. This aspect of the model comprises two dimensions for value measurement, tangible and intangible value. In measuring BIM business value, asset owners will have to understand how outcomes affect business value and determine the point at which business value is measured. It is pertinent for the asset manager to put into perspective value content creators, requirements of value extractors and managers, and the needs of the value users (Cronk and Fitzgerald, 1999).

Measuring tangible value requires organisations to deploy the right tools and techniques to be able to capture the outcomes of the system. On the other hand, measuring intangible value is more challenging, and many asset managers feel that it is impossible to measure it. Therefore, to be able to capture intangible value, managers will have to link intangible outcomes to tangible outputs that are recognisable within business processes (Carayannis, 2004). This can be done through substitution of attributes in comparison with outputs and measurable metrics. The organisation will have to specify which tangible outcome it wishes to measure from its internal BIM Value Realisation Plan (VRP) that is developed independently. Furthermore, asset owners will have to rely on proxies or indirect measures in measuring intangible value (Blair and Wallman, 2001). Similarly, Boyle (2004) notes that there are several indirect metrics for measuring intangible phenomena; to measure poverty, governments measure people on welfare; to measure intelligence, schools measure exam results or IQ; to measure health, hospitals measure blood cells; and to measure success, individuals or organisations measure money. In the same manner, the framework presented in this study suggests this indirect approach to measuring intangible value. Although this approach may capture a fraction of what organisations intend to achieve, certainly a crude estimate is better than none at all (Marr, 2007). By this element, the study provides a holistic framework that will enable organisations to capture both tangible and intangible value of BIM implementation in AM.

8.4.1.4.1 TANGIBLE VALUE

This is a procedural technique of measuring the tangible value of BIM implementation in the operation and use stage. This study presents a four-step process of measuring tangible business value; observe, assess, measure and value. This is shown in Figure 8.9.

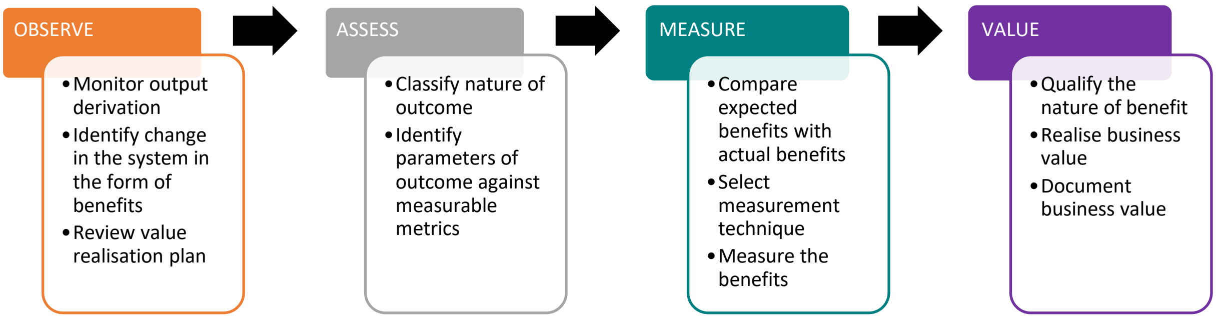


Figure 8.9: Tangible benefit measurement process

- **Observe:** The changes to the system have to be observed closely and accurately documented. This step should assess the value realisation plan that was produced at the beginning of the investment lifecycle and review the target benchmarks. It is important to connect the benefit identification with the value realisation plan and business case so that the business value that BIM could deliver are aligned with the organisation's business strategy.
- **Assess:** The next step is to assess the nature of the change, whether it is positive or negative. This can only be determined if the outcomes are properly classified to be measured against organisational efficiency metrics such as time, cost and effort in operations.
- **Measure:** At this stage, a drawdown list of expected business value from the value realisation plan and business case is compared with the actualised tangible outcomes from the system. After identification, the measurement technique is selected. Value is measured using the preferred identified technique by the asset owner.

- **Value:** The benefits or dis-benefits are realised at the end of the process. The nature of the identified BIM business value and its dimensions are determined at the user, system, business or ecosystem level. The organisation will have to document the value realised for continuous improvement.

8.4.1.4.2 INTANGIBLE VALUE

This is a procedural technique of measuring the intangible value of BIM implementation in the operations and use stage. This study develops a four-step process of measuring intangible business value; observe, link, measure and value (Carayannis, 2004; Nogeste and Walker, 2005). This is shown in Figure 8.10.

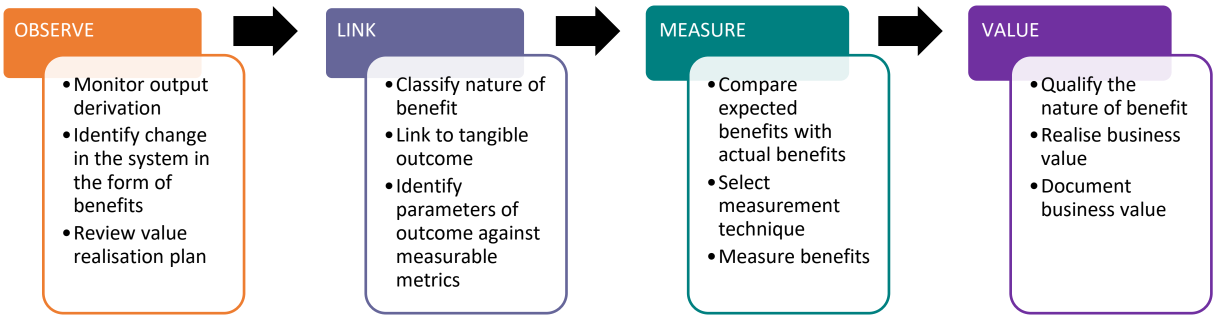


Figure 8.10: Intangible benefit measurement process

- **Observe:** The change to the system is observed closely and accurately documented. The process of identifying intangible output is challenging and complicated; hence managers will have to cast a wide net over so many outcomes from the system. The value realisation plan and business cases should be reviewed so that benchmarks are identified.
- **Link:** The next step will involve linking the observed phenomenon to measurable organisational metrics. This process is further explained in Section 8.4.1.4.3 (Figure 8.11). Intangible outputs are to be linked to tangible outcomes for measurement. This process is exploratory as organisations have to develop appropriate outcome pairing techniques.
- **Measure:** The next step is to compare the newly observed phenomenon with already existing organisational standards or results. This is the stage where business value

planned for are monitored for realisation. The appropriate measurement technique is adopted, and the value is identified.

- **Value:** The benefits or dis-benefits are realised at the end of the process. The nature of the identified BIM business value and its dimension is determined at the user, system, business or ecosystem level. Finally, the business value is properly documented and established.

8.4.1.4.3 LINKING INTANGIBLE VALUE TO TANGIBLE VALUE

One of the difficult tasks of measuring intangible value is identifying a metric with which to measure it. Also, measuring intangibles is very difficult because it is not always possible to quantify those values in absolute terms without any degree of subjectivity. Whether intangibles are assigned with value or not, these business values still remain significant to achieving organisational objectives (Remenyi, 2000). Bakis *et al.* (2006) evaluate the inherent problems of quantifying business value and the difficulties associated with intangible value and demonstrated a business value linkage diagram for the identification of the business value of IT-based investments. The framework presented in this study adopts a similar approach in order to measure or quantify the intangible business value of BIM. Therefore, intangible value will have to be linked with tangible outcomes. Business value linkage is a technique which assists asset managers in identifying value and understanding the process through which value is created within business processes.

This study proposes a concept map used to link intangible to tangible value through a linkage diagram. The BIM capability of the system is observed in order to identify the processes it affects and the value it delivers. Subsequently, the intangible business value is identified. The possible semi-tangible business value derived as a result of the intangible business value are also acknowledged. The linking of semi-tangible business value to tangible business value is done for ease of measurement. Finally, intangible value linked to tangible outcomes derived from the BIM-based process may be evaluated using any value measurement technique. The concept map proposes a simple four-step process, but in some cases, it can be shorter or longer. Whilst using this process, asset owners need to establish benchmarks so as to improve linkage and measurement metrics over time. This is shown in Figure 8.11:

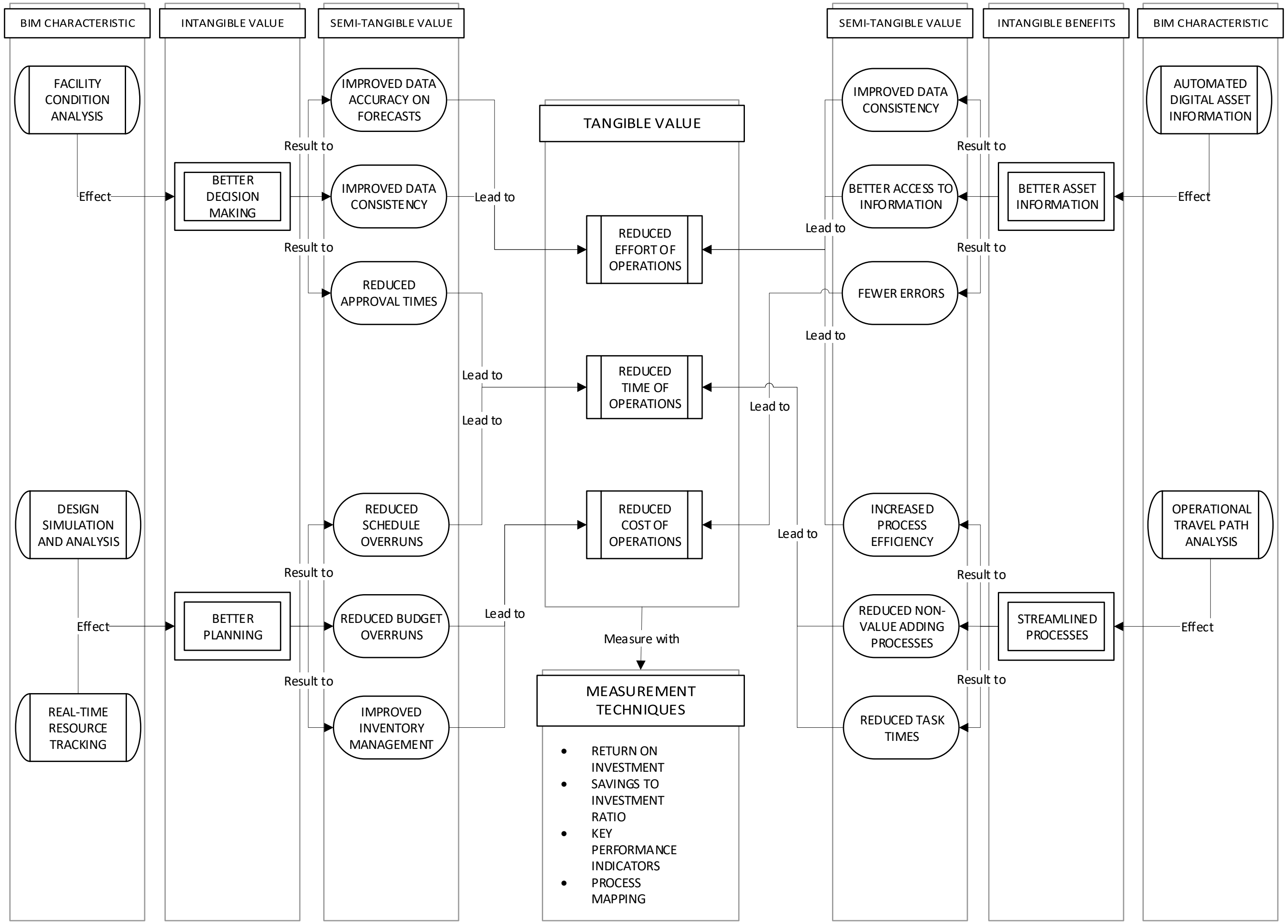


Figure 8.11: A concept map for linking intangible value to tangible value for BIM-based processes

8.4.1.5 BIM BUSINESS VALUE REALISATION (BVR) DIMENSION

The business value realisation dimension is the element of the model where value is realised. Accordingly, the types of values that can be realised in this level have been highlighted in Chapter 6 they are; management, commerce, efficiency, industry, user and technology value. These values can be realised at the user, system, business and ecosystem level (Cronk and Fitzgerald, 1999). The realised values in this element are tracked, managed and measured through the *Drivers* element of the BIMAsset VRM.

8.4.1.5.1 USER DIMENSION

The user-related dimension reports business value as a result of the user characteristics. These are skills and attributes that result in the effective and efficient utilisation of the system by end-users. These include, but are not limited to, improved employee morale, enhanced employee efficiency and reduced workload, which are business values derived at the user level.

8.4.1.5.2 SYSTEM DIMENSION

The system-dependent dimension describes business value as a result of system properties. These attributes influence the system through their relationship to business process impacts and by improving its performance. These include, but are not limited to, process efficiency and process effectiveness that are values derived at the system dimension.

8.4.1.5.3 BUSINESS DIMENSION

The business-related dimension represents outcomes as business value that result from organisational-level characteristics. These attributes have an effect on the business-level factors that relate to strategic alignment. These include, but are not limited to, cost efficiency, client satisfaction and improved reputation, which are values derived at the business level.

8.4.1.5.4 ECOSYSTEM DIMENSION

The ecosystem dimension comprises the outcomes of business value in relation to the supply chain, platform economy and platform service-related characteristics. These attributes have an effect on organisations that have integrated their business models within social, service or technology-based frameworks. These include, but are not limited to: cost efficiency, enhanced ecosystem productivity and long-term relationships as values that are derived at the ecosystem level.

8.4.2 BIMASSET FLOWCHART

For easy comprehension of the BIMAsset VRM, the study develops a BIMAsset flowchart to demonstrate the elements and their relationship during value realisation. Grieves and Vickers (2017) suggests two types of outcomes from a BIMAsset system, and they are; predicted and unpredicted. These are shown in Figure 8.12:

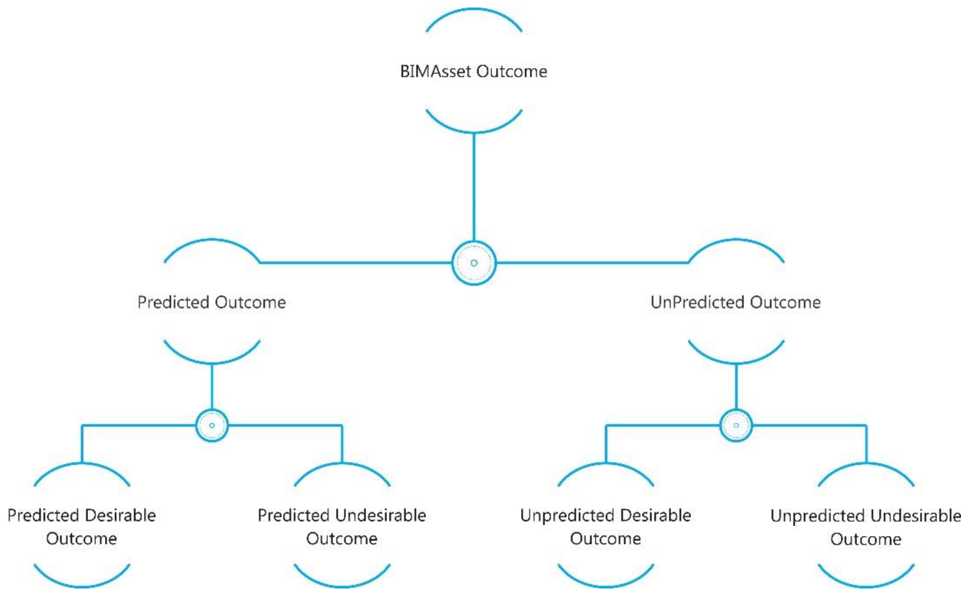


Figure 8.12: BIMAsset outcomes adapted from Grieves and Vickers (2017)

Through the proposed BIMAsset flowchart (Figure 8.13), the BIMAsset VRM in this study seeks to guide the asset manager to validate the following:

- attainment of predicted desirable outcomes;
- elimination of predicted undesirable outcomes;
- discovery of unpredicted desirable outcomes in order by establishing formal organisational metrics for value realisation management; and
- identification of unpredicted undesirable outcomes for continuous improvement and future elimination.

Figure 8.13 shows the BIMAsset flowchart highlighting the intricate links between tasks, activities and elements within the BIMAsset VRM. The diagram demonstrates the influencers, input, core, output, drivers and the BIM BVR dimension. Also, in line with the findings of the Chapters 6 and 7, the BIMAsset flowchart demonstrates the key AM business processes that drive BIM business value that were identified in Chapter 7, together with the types of values identified in Chapter 6. Furthermore, the flowchart aims to guide asset managers to track, manage, measure and realise BIM business value from the outcomes of the BIM-based AM system.

In implementing the BIMAsset VRM, it highlights that the people, process and technology influence the system. These influencers guide and control the entire value realisation management activity. Firstly, the process starts with the input, where Information from pre-handover phases or data from preceding AM tasks are entered into the system for AM purposes based on task requirements. These datasets are then processed for AM tasks such as (but not limited to the following): BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management. These tasks are processed and governed by management, operational and technological controls. Furthermore, the execution of these tasks is facilitated by a Common Data Environment (CDE) platform within the owner-operator organisation. The next stage is the output, which are outcomes of the BIM-based AM processes. These are in the form of management and operational maintenance KPIs. Outcomes of BIM-based AM tasks are utilised by asset managers for decision-making or as input for succeeding tasks. The following activity will be the evaluation of BIM-based outcomes. Furthermore, results are evaluated, and classifications are made based on the nature of business value. The business values identified could be: management, commerce, efficiency, industry, user and/or technology value. The four-step framework for measuring tangible and/or intangible value will be utilised here. The planned or expected business value are then juxtaposed against the actual business value in order to document the results. Lastly, value is realised or qualified at different levels of the organisation. These could be at the user, system, business and/or ecosystem level.

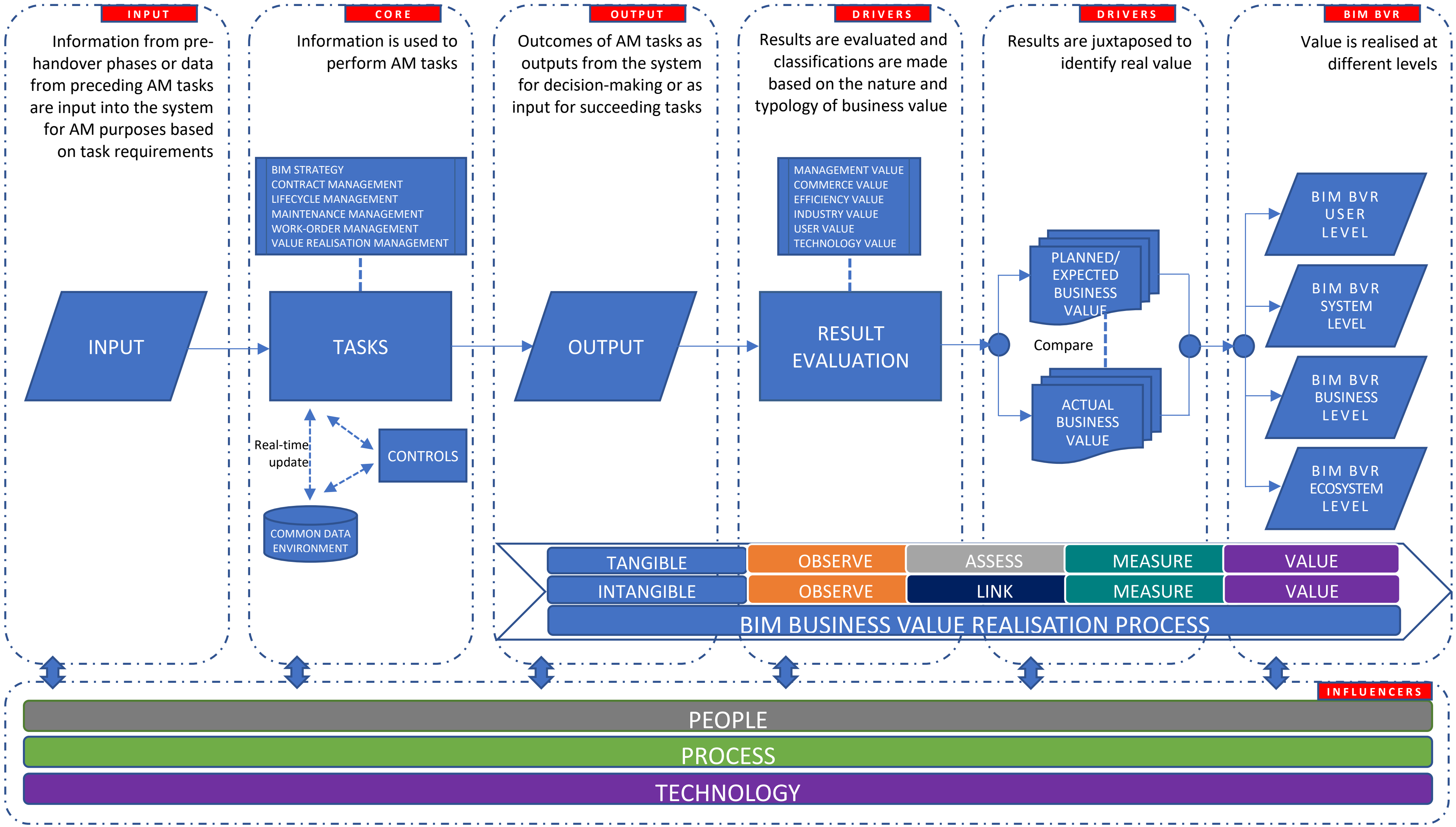


Figure 8.13: BIMAsset Flowchart

8.4.3 BIMASSET MATURITY MODEL (BAMM)

This section reviews the BAMM tool and highlights its development and applicability in AM tasks as a guide for asset managers. Furthermore, the BAMM tool is aimed at complementing the BIMAsset VRM during implementation as it facilitates organisational appraisal of business processes. The BAMM is developed in this study as a result of the identified knowledge gap (Section 2.9) and need to evaluate BIM-based AM processes in relation to value realisation management (Chapter 7). The understanding of organisational maturity is crucial for asset owners to be able to realise BIM business value. Hence, the premise for the development of the BAMM. This is because the more organisations are aware of the maturity of their key business processes the greater tendency they have in improving business process capability (Harmon, 2004).

The BAMM aims to enable an owner-operator organisation to determine its strengths and weaknesses within key BIM-based AM business processes. In order for an organisation to move through the levels of maturity, an organisational culture of continuous improvement should be established. The BAMM consists of five sequential tiers of maturity that demonstrate the development of an organisation in relation to its potential to realise BIM business value. They are: Tier 1: Ad-hoc (19-35); Tier 2: Defined (36-53); Tier 3: Managed (54-71); Tier 4: Integrated (72-89); and Tier 5: Optimised (90). The aggregate score from the BAMM appraisal sheet qualifies the level maturity of the organisation. The BAMM appraisal assessment sheet and criteria presented in Section 8.4.4 is developed to simplify organisational appraisal by breaking down the evaluation of BIM capability from the perspective of six business activity systems in relation to three functional drivers. The score is then aggregated on the assessment sheet and summarised in Figure 8.14.

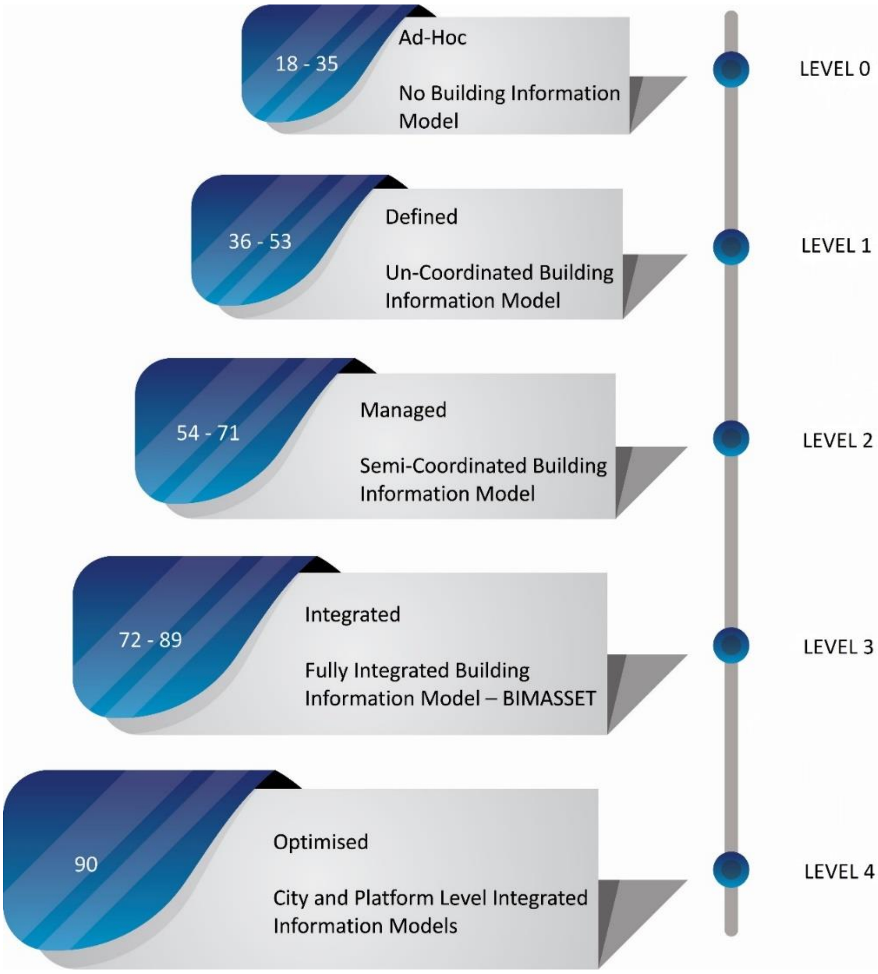


Figure 8.14: BIMAsset Maturity Model (BAMM)

8.4.3.1 LEVEL 1 – AD-HOC

NO BUILDING INFORMATION MODEL

The overall characteristic of this level is that there are ad-hoc BIM-based processes within the organisation. Documentation is in variants of 3D, 2D electronic or paper-based formats with no specific requirements for information models. Also, no COBie information is delivered from the design and construction stages.

8.4.3.2 LEVEL 2 – DEFINED

UN-COORDINATED BUILDING INFORMATION MODEL

The general organisational trait of this tier is having un-coordinated building information models delivered at the end of the design and construction phases. Documentation may lack organisational-level standards for requirements and use within BIM-based AM processes.

8.4.3.3 LEVEL 3 – MANAGED

SEMI-COORDINATED BUILDING INFORMATION MODEL

The common organisational attribute of this stage is the existence of semi-coordinated building information models. COBie-level information requirements are defined, and the delivery process is arbitrary. Here, it is common that the owner-operator organisation lacks a robust strategy for EIR documentation.

8.4.3.4 LEVEL 4 – INTEGRATED

FULLY INTEGRATED BUILDING INFORMATION MODEL – BIMAsset

The main organisational feature of this phase is the existence of fully integrated building information models with access to real-time data at the building or facility level. The BIM-based AM system operates with smooth interoperability, and AM information is searchable for analysis. Here, the asset owner possesses a robust strategy for operational information requirement documentation. At this stage of maturity, the constantly updated virtual model (BIMAsset) will have an intrinsic value in its own right.

8.4.3.5 LEVEL 5 – OPTIMISED

CITY AND PLATFORM LEVEL INTEGRATED INFORMATION MODELS

The general organisational characteristic of this level is the management of activities at the multi-facility system level, including fully integrated systems combining general access with city-level information. The BIM-based AM system operates with smooth interoperability including the availability of asset information at the multi-facility or city level.

8.4.4 BIMASSET MATURITY MODEL APPRAISAL CRITERIA

The BAMM tool is developed through abductive research methods, as discussed in Section 8.3.1. A number of studies have utilised a similar approach in developing maturity models (SEI, 1994; Sarshar *et al.*, 2000; SEI, 2006; Succar, 2010). This study utilises the five levels of BIM maturity as proposed in the BIMMI (Succar, 2010), they are; Ad-hoc, Defined, Managed, Integrated, and Optimised. The level of maturity is allocated a scale of 1 – 5 points. The BAMM tool proposed in this study takes into perspective aspect of BIM governance within organisations. Hence, People, Process and Technology are added to the model and are given equal weightings (Bosch, Volker and Koutamanis, 2015; Prodan, Prodan and Purcarea, 2015; Alreshidi, Mourshed and Rezgui, 2017). The scoring for each option is as follows:

- Ad-hoc – 1 Point
- Defined – 2 Points
- Managed – 3 Points
- Integrated – 4 Points
- Optimised – 5 Points

In the context of the BAMM tool, the BIM governance dimensions are referred to as functional drivers. Furthermore, from the case study interviews, the vital BIM-based business processes in relation to value realisation in AM are referred to as activity systems. These two elements are established as the main focus of analysis. The key activity systems are BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management.

During evaluation, each company is appraised based on the maturity of people, process and technology against BIM strategy, contract management, lifecycle management, maintenance management, work-order management, and value realisation management business processes. The overall scores for each governance element (people, process and technology) based on the activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management) is aggregated into a total numerical figure in the BAMM assessment sheet (Figure 8.15):

ORGANISATIONAL MATURITY ASSESSMENT SHEET								
S/NO	DESCRIPTION		COMPANY NAME					
			1	2	3	4	5	
1	BIM STRATEGY							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
2	CONTRACT MANAGEMENT							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
3	LIFECYCLE MANAGEMENT							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
4	MAINTENANCE MANAGEMENT							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
5	WORK-ORDER MANAGEMENT							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
6	VALUE REALISATION MANAGEMENT							
	A. PEOPLE							
	B. PROCESS							
	C. TECHNOLOGY							
	TOTAL SCORE		NUMERICAL VALUE					

Figure 8.15: BAMM assessment sheet

8.4.4.1 ACTIVITY SYSTEMS AND FUNCTIONAL DRIVERS

From the case study interviews, the activity systems are acknowledged to have a vital impact on business processes performed by asset managers in order to be able to derive BIM business value. The scoring of each activity system from the dimensions of people, process and technology should consider the following organisational characteristics in evaluating the activity systems:

- **BIM Strategy:** Organisational BIM approaches; change management; performance management; stakeholder management; organisational policy for utilising BIM-based processes; and definition of specific organisational needs for BIM-based processes.
- **Contract Management:** Performance monitoring; invoice tracking; checking compliance; and tendering.

- **Lifecycle Management:** Organisational BIM standards covering asset development stages; data integration across asset development phases; process standardisation; technological capability; and human inclusion.
- **Maintenance Management:** Organisational culture of utilising BIM in reactive, preventive, predictive, proactive and passive based maintenance practices.
- **Work-order Management:** Organisational task management protocols; process standardisation and workflows; identification of user characteristics; definition of individual and organisational data needs; automated cost estimates and invoicing; and supply chain integration.
- **Value Realisation Management:** Formulation of organisational performance targets; establishment of value measurement techniques; definition and monitoring of KPIs; change management strategies; and stakeholder management strategies.

Furthermore, the scoring of each functional driver from the perspective of each activity system considered the following organisational characteristics:

- **People:** Organisational strategy; BIM implementation strategy; collaboration; staffing; training; and business process capability of every activity system.
- **Process:** BIM standards; organisational BIM objectives; defined roles; effective use of data; supply chain integration; asset lifecycle integration; and value realisation management of every activity system.
- **Technology:** BIM systems; IT Systems; AM Systems; FM systems; organisational systems architecture; interoperability; data integrity; and data accessibility of every activity system.

Figure 8.16 shows the criteria for assessment in relation to the established 1 – 5 Likert scales.

8.4.4.2 BAMM ASSESSMENT CRITERIA

The BAMM tool has the following assessment criteria. This is shown in Figure 8.16:

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
1	**BIM STRATEGY**	People	The organisational objectives of BIM are ambiguous and lack effective communication. Lack of stakeholder engagement and participation is common organisation-wide. Organisational departments are siloed, and strategic initiatives are not mutual.	Organisational BIM strategy is defined, but communication is limited. Stakeholders understand the business value of collaboration, partnership and BIM-based processes organisation-wide. Stakeholder involvement is limited in the implementation of strategic initiatives.	Organisational BIM strategy is properly defined, communicated and accepted by all stakeholders. The organisation understands its operational information requirements for executing BIM-based processes. Stakeholder engagement is encouraged, and shared understanding is developed within the organisation.	Organisational BIM strategy is comprehensive, established and aligned to business objectives. The organisation has defined its organisational and asset information requirements. Stakeholder integration and group thinking is established organisation-wide. Strategic partnerships are identified, activated and aligned to business objectives.	Organisational BIM strategy is expansive, institutionalised and continuously improved whilst incorporating other aspects of the built environment. The organisation understands the ecosystem information requirements and plans to deliver them. Organisational BIM strategy covers whole lifecycle asset development and operations. Organisational involvement of external partners is strategic, long-term and based on collaborative procurement models with open communication and shared values.
		Process	Organisational strategy on the implementation of BIM is not properly defined. Lack of effective inter and intra organisational collaboration and communication is common organisation-wide.	Organisational BIM strategy is limited to critical business activities or assets. There exist inconsistent and reactionary processes to all aspects of organisational business processes.	Organisational BIM strategy covers operational aspects of business processes that are defined, communicated and accepted. BIM-based process protocols are properly determined and acknowledged by all stakeholders. Stakeholders are trained for continual upskilling. BIM-based processes are re-engineered to organisational and asset information requirements. Inter and intra organisational collaboration and communication is encouraged organisation-wide.	Organisational BIM strategy is established in both management and operational business processes. BIM-based process protocols are established and aligned to business objectives. Collaboration is formalised with an established process of feedback. BIM-based processes deliver outcomes stated in both organisational and asset information requirements. Inter and intra organisational collaboration and communication is established and aligned to business objectives organisation-wide.	Organisational BIM strategy is institutionalised and continuously improved in both management and operational business processes. BIM-based processes are embedded in organisational and supply chain routines. Organisational strategy covers business processes of the platform economy and services that are to be integrated organisation-wide. Organisational strategy covers BIM-based processes that will deliver outcomes based on the AEC industry ecosystem information requirements.
		Technology	Organisational BIM strategy lacks awareness on suitable technological systems to adopt for BIM-based processes. Lack of effective strategies on inter and intra organisational interoperability and communication is common organisation-wide.	Organisational BIM strategy is defined and covers key technologies to be utilised but is limited to critical business activities or assets. The organisation understands the strategic benefit of systems interoperability and integration.	Organisational BIM strategy covers technologies to be utilised for operational business processes that are defined, communicated and accepted. Organisational BIM strategy covers asset-level integration in terms of information delivery. Organisation BIM-strategy covers identified technologies and interoperability requirements. Organisational BIM strategy actively encourages informal networking.	Organisational BIM strategy covering technologies is comprehensive, established and aligned to business objectives in both management and operational business processes. Organisational BIM strategy covers portfolio-level integration in terms of information delivery. Organisational BIM strategy covers systems integration with smooth interoperability organisation-wide.	Organisational BIM strategy on technologies is institutionalised and continuously improved in both management and operational business processes. Organisational BIM strategy covers technologies that have platform economy functionality and city-level integration. Organisational BIM strategy comprises of a roadmap for smooth interoperability across systems in the AEC industry ecosystem.

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
2	**CONTRACT MANAGEMENT**	People	The organisational objectives of utilising BIM in asset contracts management is ambiguous and lack effective communication. Lack of stakeholder engagement and participation across phases of contract administration is common organisation-wide. Organisational departments are siloed across all execution areas and phases of contracts management.	Organisational objectives of utilising BIM in asset contracts management are defined, but communication is limited. Stakeholders understand the business value of collaboration, partnership and BIM-based processes in contracts management organisation-wide. Stakeholder involvement is limited in the execution of contracts management tasks across all activity areas and phases.	Organisational objectives of utilising BIM in asset contracts management are properly defined, communicated and accepted by all stakeholders. The organisation understands its operational information requirements for executing BIM-based processes and plans to integrate them in contracts management. Stakeholder engagement is encouraged, and shared understanding is developed within the organisation and across all execution areas and phases of contracts management.	Organisational objectives of utilising BIM in asset contracts management are comprehensive, established and aligned to business objectives. The lifecycle contractual information requirements of assets are properly defined. Stakeholder integration and group thinking in contracts execution and management across all activity areas and phases is established organisation-wide. A lifecycle approach to partnership in contracts management is activated and aligned to business objectives.	Organisational objectives of utilising BIM in asset contracts management is expansive, institutionalised and continuously improved whilst incorporating other stakeholders within the AEC industry. The organisation understands the lifecycle contractual information requirements of the ecosystem and plans to deliver them. A whole lifecycle approach to execution of contracts management across all activity areas and phases is established. Partnerships in relation to strategic maintenance are activated beyond one asset lifecycle within the AEC industry ecosystem.
		Process	Organisational processes of utilising BIM in asset contracts management are not properly defined. Lack of effective inter and intra organisational collaboration and communication during the execution of contracts management tasks across all activity areas and phases organisation-wide.	Organisational processes of utilising BIM in asset contracts management is limited to critical business activities. There exist inconsistent and reactionary processes during the execution of contracts management tasks across all activity areas and phases.	Organisational processes of utilising BIM in asset contracts management cover operational aspects of business processes. These processes are defined, communicated and accepted by all stakeholders. Stakeholders are trained for continual upskilling in contracts management activities. BIM-based processes are re-engineered to deliver contracts management data as per organisational and asset information requirements. Inter and intra organisational collaboration and communication is encouraged during the execution of contracts management tasks across all activity areas and phases organisation-wide.	Integrated and collaborative operations are established in the contract management of assets. Organisational processes of utilising BIM in contracts management of asset data in both management and operational business processes are established and aligned to business objectives. Inter and intra organisational collaboration and communication is established with feedback in the execution of contracts management tasks across all activity areas and phases.	Organisational processes of utilising BIM in asset contracts management are institutionalised and continuously improved in both management and operational business processes. BIM-based processes of contracts management are embedded in organisational and supply chain routines. Platform economy and services are integrated into overall organisational contracts management activities.
		Technology	Organisation lacks awareness on suitable technological systems to adopt for BIM-based contracts management processes. Lack of effective inter and intra organisational interoperability and communication in the execution of contracts management tasks across all activity areas and phases organisation-wide.	Organisational capability in asset contracts management is defined and covers key technologies to be utilised but is limited to critical business activities or assets. The organisation understands the benefit of systems interoperability and integration in the execution of contracts management tasks across all activity areas and phases.	Organisational capability in asset contracts management covers technologies to be utilised for operational business processes that are defined, communicated and accepted. The technological systems have the capability for asset-level integration of contracts management data and information delivery. Technology related interoperability requirements for contracts management are defined. Informal networking is encouraged organisation-wide.	Organisational capability in asset contracts management is comprehensive, established and aligned to business objectives in executing both management and operational business processes. The technological systems have the capability for portfolio level integration in terms of contracts management data and information delivery. Systems integration in contracts management is achieved with minor interoperability issues.	Organisational capability in asset contracts management is institutionalised and continuously improved in executing both management and operational business processes. The technological systems have platform economy functionality and city-level integration. Smooth interoperability in contracts management is attained across systems in the AEC industry ecosystem.

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
3	**LIFECYCLE MANAGEMENT**	People	The organisational objectives of utilising BIM in lifecycle management of assets is ambiguous and lacks proper communication. Lack of stakeholder participation and communication across asset development phases. Organisational departments are siloed during asset development and operations.	Organisational objectives of utilising BIM in lifecycle management of assets is defined, but communication is limited. Organisation understands the benefit of collaboration, partnership and BIM-based processes in the lifecycle management of assets. Stakeholder involvement is limited in asset development and operations.	Organisational objectives of utilising BIM in lifecycle management of assets is properly defined, communicated and accepted by all stakeholders. The organisation understands its employer information requirements from the BIM-based process and plans to integrate them in all lifecycle phases. Stakeholder engagement is encouraged, and shared understanding is developed within the organisation during asset development and operations.	Organisational objectives of utilising BIM in lifecycle management of assets is comprehensive, established and aligned to business objectives. The lifecycle information requirements of assets are properly defined. There exists stakeholder integration and group thinking during asset development and operations. A lifecycle approach to partnerships is activated and aligned to business objectives.	Organisational objectives of utilising BIM in lifecycle management of assets is expansive, institutionalised, continuously improved, including other ecosystem stakeholders. The organisation understands the lifecycle requirements of the ecosystem information requirements and plans to deliver them. A whole lifecycle approach to asset development is established. Partnerships are activated beyond one project lifecycle within the industry ecosystem.
		Process	Organisational processes of utilising BIM in lifecycle management are not properly defined. Lack of effective inter and intra-organisation collaboration and communication during asset development and operations.	Organisational processes of utilising BIM in lifecycle management is limited to critical business activities. There exist inconsistent and reactionary processes during asset development and operations.	Organisational processes of utilising BIM in lifecycle management covers the operational aspect of business processes. These processes are defined, communicated and accepted by all stakeholders. Employees are trained for continual upskilling in lifecycle management activities. BIM-based processes are re-engineered to deliver asset lifecycle data. Inter and intra-organisation collaboration and communication is encouraged during asset development and operations.	Integrated Product Delivery (IPD) is established in the lifecycle management of asset data. Organisational processes of utilising BIM in lifecycle management of asset data in management and operational business processes are established and aligned to business objectives. Inter and intra-organisation collaboration and communication is established with feedback during asset development and operations	Organisational processes of utilising BIM in lifecycle management are institutionalised and continuously improved in management and operational business processes. BIM-based processes of lifecycle data management processes are embedded in organisational and supply chain routines. Platform services and economy business are integrated into overall organisational lifecycle management.
		Technology	Organisational lacks organisational awareness on suitable technological systems to adopt for BIM-based lifecycle management processes. Lack of effective inter-organisational and intra-organisational interoperability and communication during asset development and operations.	Organisational capability in lifecycle management is defined and covers key technologies to be utilised but limited to critical business activities or assets. The organisation understands the benefit of systems interoperability and integration during asset development and operations.	Organisational capability in lifecycle management covers technologies to be utilised for operational business processes that are defined, communicated and accepted. The technological systems have the capability of asset-level integration of lifecycle asset data and information delivery. Organisation has defined technologies and interoperability requirements for lifecycle management. Informal networking is encouraged.	Organisational capability in lifecycle management is comprehensive, established and aligned to business objectives in executing management and operational business processes. The technological systems have the capability of portfolio level integration in terms of lifecycle asset data and information delivery. Systems integration in lifecycle management is achieved with minor interoperability issues.	Organisational capability in lifecycle management is institutionalised and continuously improved in executing management and operational business processes. The technological systems have the capability of integrating platform functionality and City-level integration. Smooth interoperability in lifecycle management between systems is attained.

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
4	**MAINTENANCE MANAGEMENT**	People	The organisational objectives of utilising BIM in asset maintenance management is ambiguous and lack effective communication. Lack of stakeholder engagement and participation in the development of maintenance strategies is common organisation-wide. Organisational departments are siloed in the development and execution of maintenance strategies.	Organisational objectives of utilising BIM in asset maintenance management are defined, but communication is limited. Stakeholders understand the business value of collaboration, partnership and BIM-based processes in maintenance management organisation-wide. Stakeholder involvement is limited in the development and execution of maintenance strategies.	Organisational objectives of utilising BIM in asset maintenance management are properly defined, communicated and accepted by all stakeholders. The organisation understands its operational information requirements for executing BIM-based processes and plans to integrate them in maintenance management. Stakeholder engagement is encouraged, and shared understanding is developed within the organisation during the development and execution of maintenance strategies.	Organisational objectives of utilising BIM in asset maintenance management are comprehensive, established and aligned to business objectives. The strategic maintenance information requirements of assets are properly defined. Stakeholder integration and group thinking during the development and execution of maintenance strategies is established organisation-wide. A lifecycle approach to partnership in maintenance management is activated and aligned to business objectives.	Organisational objectives of utilising BIM in asset maintenance management is expansive, institutionalised and continuously improved whilst incorporating other stakeholders within the AEC industry. The organisation understands the strategic maintenance requirements of the ecosystem and plans to deliver them. A whole lifecycle approach to the development and execution of maintenance strategies is established. Partnerships in relation to strategic maintenance activities are activated beyond one asset lifecycle within the AEC industry ecosystem.
		Process	Organisational processes of utilising BIM in asset maintenance management are not properly defined. Lack of effective inter and intra organisational collaboration and communication in the development and execution of maintenance strategies organisation-wide.	Organisational processes of utilising BIM in asset maintenance management is limited to critical business activities. There exist inconsistent and reactionary processes during the development and execution of maintenance strategies organisation-wide.	Organisational processes of utilising BIM in asset maintenance management cover operational aspects of business processes. These processes are defined, communicated and accepted by all stakeholders. Stakeholders are trained for continual upskilling in asset maintenance management activities. BIM-based processes are re-engineered to deliver strategic maintenance data as per organisational and asset information requirements. Inter and intra organisational collaboration and communication is encouraged during the execution of maintenance strategies organisation-wide.	Integrated and collaborative operations are established in the maintenance management of assets. Organisational processes of utilising BIM in maintenance management of asset data in both management and operational business processes are established and aligned to business objectives. Inter and intra organisational collaboration and communication is established with feedback in the development and execution of maintenance strategies organisation-wide.	Organisational processes of utilising BIM in asset maintenance management are institutionalised and continuously improved in both management and operational business processes. BIM-based processes of strategic asset maintenance are embedded in organisational and supply chain routines. Platform economy and services are integrated into overall organisational maintenance management activities.
		Technology	Organisation lacks awareness on suitable technological systems to adopt for BIM-based maintenance management processes. Lack of effective inter and intra organisational interoperability and communication in the execution of maintenance strategies organisation-wide.	Organisational capability in asset maintenance management is defined and covers key technologies to be utilised but is limited to critical business activities or assets. The organisation understands the benefit of systems interoperability and integration in the execution of maintenance strategies.	Organisational capability in asset maintenance management covers technologies to be utilised for operational business processes that are defined, communicated and accepted. The technological systems have the capability for asset-level integration of strategic maintenance data and information delivery. Technology related interoperability requirements for maintenance management are defined. Informal networking is encouraged organisation-wide.	Organisational capability in asset maintenance management is comprehensive, established and aligned to business objectives in both executing management and operational business processes. The technological systems have the capability for portfolio-level integration in terms of strategic maintenance data and information delivery. Systems integration in maintenance management is achieved with minor interoperability issues.	Organisational capability in asset maintenance management is institutionalised and continuously improved in executing both management and operational business processes. The technological systems have platform economy functionality and city-level integration in maintenance management. Smooth interoperability in maintenance management is attained across systems in the AEC industry ecosystem.

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
5	**WORK-ORDER MANAGEMENT**	People	The organisational objectives of utilising BIM in asset work-order management is ambiguous and lack effective communication. Lack of stakeholder engagement and participation in operational management of work-orders is common organisation-wide. Organisational departments are siloed during the execution of work-orders.	Organisational objectives of utilising BIM in asset work-order management are defined, but communication is limited. Stakeholders understand the business value of collaboration, partnership and BIM-based processes in work-order management organisation-wide. Stakeholder involvement is limited in the development and execution of work-orders.	Organisational objectives of utilising BIM in asset work-order management are properly defined, communicated and accepted by all stakeholders. The organisation understands its operational information requirements for executing BIM-based processes and plans to integrate them in work-order management. Stakeholder engagement is encouraged, and shared understanding is developed within the organisation during the development and execution of work-orders.	Organisational objectives of utilising BIM in asset work-order management are comprehensive, established and aligned to business objectives. The operational maintenance information requirements of assets are properly defined. Stakeholder integration and group thinking during the development and execution of work-orders is established organisation-wide. A lifecycle approach to partnership in work-order management is activated and aligned to business objectives.	Organisational objectives of utilising BIM in asset work-order management is expansive, institutionalised and continuously improved whilst incorporating other stakeholders within the AEC industry. The organisation understands the operational maintenance requirements of the ecosystem and plans to deliver them. A whole lifecycle approach to development and execution of work-orders is established. Partnerships in relation to operational maintenance activities are activated beyond one asset lifecycle within the AEC industry ecosystem.
		Process	Organisational processes of utilising BIM in asset work-order management are not properly defined. Lack of effective inter and intra organisational collaboration and communication in the execution of work-orders organisation-wide.	Organisational processes of utilising BIM in asset work-order management is limited to critical business activities. There exist inconsistent and reactionary processes during the development and execution of work-orders organisation-wide.	Organisational processes of utilising BIM in asset work-order management cover operational aspects of business processes. These processes are defined, communicated and accepted by all stakeholders. Stakeholders are trained for continual upskilling in work-order management activities. BIM-based processes are re-engineered to deliver operational maintenance data as per organisational and asset information requirements. Inter and intra organisational collaboration and communication is encouraged during the execution of work-orders organisation-wide.	Integrated and collaborative operations are established in the work-order management of assets. Organisational processes of utilising BIM in work-order management of asset data in both management and operational business processes are established and aligned to business objectives. Inter and intra organisational collaboration and communication is established with feedback in the development and execution of work-orders organisation-wide	Organisational processes of utilising BIM in asset work-order management are institutionalised and continuously improved in both management and operational business processes. BIM-based processes of operational asset maintenance are embedded in organisational and supply chain routines. Platform economy and services are integrated into overall organisational work-order management activities.
		Technology	Organisation lacks awareness on suitable technological systems to adopt for BIM-based work-order management processes. Lack of effective inter and intra organisational interoperability and communication in the execution of work-orders organisation-wide.	Organisational capability in asset work-order management is defined and covers key technologies to be utilised but is limited to critical business activities or assets. The organisation understands the benefit of systems interoperability and integration in the execution of work-orders.	Organisational capability in asset work-order management covers technologies to be utilised for operational business processes that are defined, communicated and accepted. The technological systems have the capability for asset-level integration of operational maintenance data and information delivery. Technology related interoperability requirements for work-order management are defined. Informal networking is encouraged organisation-wide.	Organisational capability in asset work-order management is comprehensive, established and aligned to business objectives in both executing management and operational business processes. The technological systems have the capability for portfolio-level integration in terms of operational maintenance data and information delivery. Systems integration in work-order management is achieved with minor interoperability issues.	Organisational capability in asset work-order management is institutionalised and continuously improved in executing both management and operational business processes. The technological systems have platform economy functionality and city-level integration in work-order management. Smooth interoperability in work-order management is attained across systems in the AEC industry ecosystem.

S/NO.	DESCRIPTION	BIM Dimension	BAMM Level 1: Ad-hoc	BAMM Level 2: Defined	BAMM Level 3: Managed	BAMM Level 4: Integrated	BAMM Level 5: Optimised
6	**VALUE REALISATION**	People	The organisational objectives of business value realisation of BIM-based processes are ambiguous and lack effective communication. Lack of stakeholder engagement and participation during value realisation activities is common organisation-wide. Organisational departments are siloed, and value realisation data and experiences are not mutual.	The organisational objectives of business value realisation of BIM-based processes are defined, but communication is limited. Stakeholders understand the need to realise the business value of BIM-based processes in order to justify investments. Stakeholder involvement is limited in business value realisation activities.	The organisational objectives of business value realisation of BIM-based processes are properly defined, communicated and accepted by all stakeholders. The organisation understands its operational information requirements for executing BIM-based processes and plans to justify the outcomes and validate BIM-based investments. Stakeholder engagement is encouraged, and mutual understanding is developed within the organisation during business value realisation activities.	The organisational objectives of business value realisation in relation to BIM-based processes are comprehensive, established and aligned to business objectives. The organisational, asset and operational information requirements are defined and have been matched to actual outcomes in order to establish business value formally. Stakeholder integration during business value realisation activities is established organisation-wide. Business value of strategic partnerships are evaluated and aligned to business objectives	The organisational objectives of BIM-based processes in relation to business value realisation is expansive, institutionalised and continuously improved. This includes other value streams of stakeholders within the AEC industry. The organisation understands the information needs of the ecosystem, delivers them, tracks outcomes and formally establishes business value. Organisational value realisation management covers the whole lifecycle development of the asset. Organisational involvement of external partners is strategic and value-driven with open communication and shared values.
		Process	Organisational processes, techniques and approaches for the implementation of business value realisation management is not properly defined. Lack of effective inter and intra organisational processes in business value realisation management is common organisation-wide.	The organisational processes, techniques and approaches for business value realisation of BIM-based processes is limited to critical business activities or assets. There exist inconsistent and reactionary processes in business value realisation management organisation-wide.	The organisational processes, techniques and approaches for business value realisation of BIM-based processes cover operational aspects of business processes that are defined, communicated and accepted. Value realisation management processes and protocols are properly determined and acknowledged by all stakeholders. Workshops for stakeholders are organised for continual upskilling in order to develop an understanding of value realisation management activities organisation-wide. Value realisation processes are re-engineered to track and document BIM business value in relation to process outcomes organisation-wide.	The organisational processes, techniques and approaches for business value realisation of BIM-based processes are established in both management and operational business processes. Value realisation management process protocols are established and aligned to business objectives. Value realisation management is formalised with an established process of feedback. Value realisation management processes monitor, track and manage business value in the organisation.	The organisational processes, techniques and approaches for business value realisation of BIM-based processes are institutionalised and continuously improved in relation to tracking value during the execution of both management and operational business processes. Value realisation management activities are embedded in organisational and supply chain routines. Value realisation from the platform economy and services are integrated into organisational business processes. Value realisation management processes cover the monitoring, tracking and management of business value in the AEC industry ecosystem.
		Technology	The organisational BIM strategy lacks awareness on suitable value realisation management tools and technologies to adopt for tracking value of BIM-based processes. Lack of effective inter and intra organisational interoperability and communication approaches in business value realisation management is common organisation-wide.	Organisational BIM strategy is defined and covers key value realisation management tools and technologies to be utilised but is limited to critical business activities or assets. The organisation understands the need for systems interoperability and integration in relation to BIM business value realisation.	Organisational BIM strategy covers the utilisation of tools and technologies in value realisation management that are utilised for operational business processes that are defined, communicated and accepted. Asset-level integration for easy monitoring and tracking the value of business process outcomes is established.	Organisational BIM strategy includes the utilisation of tools and technologies in value realisation management that are comprehensive, established and aligned to business objectives in both management and operational business processes. Portfolio-level integration for monitoring, tracking and managing business value in the organisation is established.	Organisational BIM strategy includes the utilisation of technologies in value realisation management that are institutionalised and continuously improved in management and operational business processes. Technologies have platform economy functionality and city-level integration with smooth interoperability in business value realisation activities. The monitoring, tracking and managing of business value in the AEC industry ecosystem is established.

Figure 8.16: BAMM assessment criteria

8.5 DEPLOYING THE BIMASSET VALUE REALISATION MODEL

This section presents the functions of the BIMAsset VRM. These functions have been identified from the literature review exercise. However, it should be noted that these are potential applications of the BIMAsset VRM. The testing of the application of the BIMAsset VRM in real-life use cases is outside the scope of this study. However, it is suggested for future studies.

8.5.1 FUNCTIONS OF THE BIMASSET VRM

By adopting the BIMAsset VRM in asset operations, the asset manager could positively impact the following business functions:

- BIM business value realisation management.
- Asset information management.
- Decision support.
- Resource management.
- Organisational appraisal.
- Levels of service.
- Regulatory compliance and performance.

8.5.1.1 BIM BUSINESS VALUE REALISATION MANAGEMENT

The BIMAsset VRM provides an opportunity to support the asset manager in aligning organisational objectives with the management and operational BIM-based business processes in order to track and establish business value within the organisation. It aims to ensure that planned business value is specific, measurable and realistic. The BIMAsset VRM provides a framework with a collective set of processes and practices for measuring BIM-business value in asset operations. It provides value measurement techniques for both tangible and intangible value. The BIMAsset VRM could enable the asset manager to: define planned benefits; determine planned or expected benefits; establish protocols for tracking, managing and measuring BIM business value; evaluate the outcomes of the BIMAsset system; and effectively manage BIM-based investments through a set of principles, processes and deliverables. Furthermore, the BIMAsset VRM would be vital to asset owners in: clarifying roles; defining requirements for BIM-based processes; identifying risks; engaging stakeholders; highlighting key business processes in value realisation; identifying benefits; and driving value realisation.

8.5.1.2 ASSET INFORMATION MANAGEMENT

The BIMAsset VRM provides a framework that could guide the business processes in each domain within the organisation in relation to the six elements of the model. As the output of the design and construction phases are utilised as inputs for AM tasks, these resources are consumed by every process in relation to the six activity systems and effective AInfM strategies identified in Chapters 7 and 6 of this study respectively. The BIMAsset VRM also helps to define the roles and responsibilities of the individual elements when establishing a complete and integrated approach for BIM business value realisation, and by demonstrating its applicability in AM in relation to value realisation management. BIM and other DIT are effective tools for AInfM, and Chapters 5 and 6 have demonstrated suitable implementation strategies, systems architecture and effective data governance in asset operations for adoption. The BIMAsset VRM would help ensure the delivery of: complete; accurate; timely; consistent; accessible; secure; comprehensible; shareable; and actionable data during the value realisation.

8.5.1.3 DECISION SUPPORT

The BIMAsset VRM provides an opportunity for decision support to asset managers when making asset-related judgements. This function is particularly important when verifying and validating the predicted desirable outcomes, discovering unpredicted desirable outcomes as well as identifying and eliminating failures related to the predicted and unpredicted undesirable outcomes of the BIMAsset system. It helps to guide the asset manager in collecting and collating the right asset data, which are crucial to inform management-based decisions. The BIMAsset VRM aims to provide support to the asset manager in contract management, lifecycle management, maintenance management, work-order management and value realisation management. It also seeks to guide the asset owner in developing organisational BIM strategy, which sets overarching rules that govern the above-mentioned business processes.

8.5.1.4 RESOURCE MANAGEMENT

The BIMAsset VRM provides an opportunity to enable the effective monitoring of organisational resources through the utilisation of efficient BIM-based processes in asset operations. The asset manager can monitor and manage resource allocation by ascertaining how every BIM-based factor of production within the owner-operator organisation contributes to the generation of business value. The BIMAsset VRM can enable the asset manager to effectively manage organisational resources such as finances, staffing, physical space, assets, protocols and technology during asset operations. It provides the tools and techniques for asset managers to view the management and operational KPIs in order to manage the physical assets in the most efficient way possible. The BIMAsset VRM provides opportunities to support the asset manager to determine and track performance measurement, identify risk, and control organisational resources in line with the organisational strategy and objectives of BIM business value realisation.

8.5.1.5 ORGANISATIONAL APPRAISAL

The BIMAsset VRM and BIMAsset Maturity Model (BAMM) could guide organisational appraisal in relation to six activity system which are evaluated from the dimensions of BIM governance. This provides the opportunity for asset managers to determine the strengths and weaknesses of key business activities that drive BIM business value in order to continuously improve on weaker areas so as to achieve higher maturity and increase the potential for realising BIM business value. Each maturity level contains organisational focus areas for determining organisational capability. The BAMM assessment sheet enables asset managers to aggregate scores and establish general organisational maturity levels across all activity systems. The BIMAsset VRM and BAMM serve as a reference point for an owner-operator organisation to apply value realisation practices in asset operations in order to realise BIM business value. They provide a basis for: assessing various aspects of value realisation management for asset owners; identifying aspects where there is room for improvement; demonstrating relationships between all variables and in relation to BIM business value; and a methodology that is logical and transparent for value realisation management.

8.5.1.6 LEVELS OF SERVICE

The BIMAsset VRM provides an opportunity to support the enhancement of service quality in response to AM tasks such as maintenance requests or the delivery of asset condition data through BIM-based processes. This could be enabled through management and operational

KPIs generated by the BIMAsset system. The BIMAsset VRM could positively impact on organisational readiness, which means the understanding of current levels of service that are obtainable in management and operational tasks could improve. This refers to the organisational awareness of the inputs, outputs and deliverables that are achievable at any given time. The BIMAsset VRM could guide the asset manager in terms of having the right personnel, doing the right things, communicating in the right context, using the right tools, creating the right output, measuring the right outcomes, establishing the right business value, and of which are rightly aligned with organisational goals. The awareness of the current levels of service will facilitate the development of a culture of continuous improvement within the owner-operator organisation.

8.5.1.7 REGULATORY COMPLIANCE AND PERFORMANCE

The BIMAsset VRM provides an opportunity to support the asset manager to meet regulatory targets during asset operations effectively. These could be environmental, statutory, health and safety regulations. Moreover, it aims to enable the asset manager to keep track of changes to configurations and upgrades to assets in relation to regulatory compatibility during asset operations. Data such as planned preventive maintenance data may well be needed for submittals by the asset manager to demonstrate regulatory compliance. As such, the availability of these datasets could enhance regulatory compliance and contribute business value to the organisation.

8.6 CONCLUSION

The study starts with the review of literature on the BIMAsset and reveals that the BIMAsset has the potential to impact the ability of asset managers to reduce waste in owner-operator organisations. In terms of developing the BIMAsset VRM, the findings in this chapter have indicated that: techniques of measuring value (tangible and/or intangible), real-time data update, data security, BIMAsset CDE and business value realisation dimensions (user, system, business, ecosystem) impact BIM implementation and subsequent value realisation. The findings underscore the significance of incorporating elements that cover: (i) the measurement of tangible and intangible value from BIM-based outcomes; (ii) the consideration of real-time data update, data security and BIMAsset CDE during task executions; and (iii) the qualification of BIM business value user, system, business, ecosystem levels.

The study goes on to present the BIMAsset VRM as a guide for asset owners. One of the advantages of the framework is that it helps validate desirable outcomes and prevents the failure caused by undesirable outcomes. Subsequently, the study presents the BAMM tool that aims to help asset managers appraise capability in relation to BIM business value. One of the challenges for asset owners is to understand that business value realisation is a process and not an outcome, and that value does not just materialise unless asset managers plan, identify, manage and acknowledge it. The entire process of value realisation management is about driving change and measuring outcomes. It requires continuous improvement throughout the process for asset managers to be able to identify unpredicted desirable outcomes and eliminate predicted and unpredicted undesirable outcomes. Even then, some business values may still be challenging to capture, but with persistent value monitoring and management, asset managers will be able to find metrics to measure such outcomes. This is because value only depends on the organisation and how it perceives it (Kujala and Väänänen-Vainio-Mattila, 2009). Generally, value in an organisation depends on the business model, professional genre and organisational culture. Consequently, it is worth repeating that owner-operators must have a BIM business value realisation management plan to be able to establish the value that BIM brings in asset operations.

Finally, the proposed model is conceptual in nature, and it provides the underlying foundation for developing a strategy for asset owners to consider how BIM can create value that will lead to a sustainable competitive market advantage. The benefit of the BIMAsset VRM is its applicability for BIM business value realisation for asset owners. As the title suggests, this guide provides an insight for asset managers to approach the process of measuring the tangible and intangible business value of BIM in their organisations.

8.7 CHAPTER SUMMARY

This chapter compiles the findings from the results chapters. It brings together all elements under investigation into a single BIMAsset VRM. Also, this synthesis chapter focuses on addressing the knowledge gaps of: lack of perceived value of BIM by clients; barriers of BIM implementation in AM; and weakness of BIM business value measurement techniques. The study develops a model which focuses on how BIM drives value, how the value can be captured and its applicability to AM business processes. An abductive research approach is adopted for model development. The research assumes a relativist ontological stance and a constructivist epistemological stance. The research is conducted to understand the phenomenon of lack of BIM business value realisation in AM and to develop a framework that will address those shortfalls. This study reveals that the BIMAsset system has the potential to impact the ability of asset managers to reduce waste in owner-operator organisations. The findings in this chapter underscore the significance of incorporating elements in the BIMAsset VRM that cover: (i) the measurement of tangible and intangible value from BIM-based outcomes; (ii) the consideration of real-time data update, data security and BIMAsset CDE during task executions; and (iii) the qualification of BIM business value user, system, business, ecosystem levels. An original contribution of this study is that it presents a novel framework (BIMAsset VRM) for value realisation management that will guide asset owners to derive BIM business value. One of the advantages of the BIMAsset VRM is that it helps validate desirable outcomes and prevents the failure caused by undesirable outcomes. Another original contribution is the BAMM tool which can be used to appraise capability in relation to BIM business value during asset operations. The frameworks presented in this study is not only beneficial to the asset manager but could also be utilised by the facility manager, supplier, contractor and the end-user to understand how they can measure the business value of BIM during asset operations.

CHAPTER 9

DISCUSSION

9.0 DISCUSSION

9.1 CHAPTER INTRODUCTION

The purpose of this chapter is to discuss the contextual nature of the findings in each of the results chapters and how they contribute to the overall study aim and model development. The data analysis in Chapters 4-8 presents the findings of the research. In this chapter, the main findings, including their contribution to the development of the BIMAsset Value Realisation Model (BIMAsset VRM) are discussed. These are elucidated in relation to the research objectives, of which this chapter is arranged accordingly. In Chapter 8, the main research output, which is the BIMAsset VRM was presented, and all elements of the model were discussed in a narrative format in order to make the findings presentable and easy to read. However, in this chapter, the entire research findings are synthesised in support of the researcher's interpretation and justification of each element and sub-element of the BIMAsset VRM. The identified elements and sub-elements are shown in Table 9.1. Therefore, detailed rationale and synthesis of each element of the BIMAsset VRM are further discussed in relation to the research objectives in the following sections.

9.2 DISCUSSION OF THE FINDINGS OF OBJECTIVE 1

Chapter 4 identified key operational information requirements for AM business processes and how they related to BIM. The main contribution of this part of the study is the evaluation of critical owner information requirements for BIM-based AM. The study evaluated aspects of operational information requirements such as the business sector, strategy, BIM data perspective, schematic structure and object category in relation to information requirements for AM tasks. These factors ultimately lead to business value, which is the rationale for BIM implementation by the asset owner. Another key significant contribution of this part of the study is the identification of three different strategies for operational information requirements; 'Co-development', 'Environment of Care' and 'Data Ambassadors'. Moreover, apart from the theoretical contributions, the findings in Chapter 4 provided significant guidance towards the progress of understanding of practical approaches adopted by some asset owners in the development of operational information requirements to be utilised for asset operations. Also, it demonstrated how operational information requirements are structured as a guide for asset owners seeking to define their requirements for BIM-based processes.

The findings in Chapter 4 highlighted the importance of the development of information requirements by the asset owner. Therefore, this informed the inclusion of the *Core* element and *Requisition* sub-element during the development of the BIMAsset VRM. The *Requisition* sub-element covers data specifications, level of detail or development, and activities related to information requirements. The identification of these factors related to the development of the BIMAsset VRM; including how the findings of this objective contributed in addressing the broader research aim of developing a model for asset owners to realise business value of BIM implementation in an AM system in the lifecycle of assets.

The multi-case study in Chapter 4 covered asset owners that operate their facilities within three sectors; health, education and MEP. Hence, it is acknowledged that the results could be biased towards certain sectors of the AEC industry or three asset owner types. It is also acknowledged that the findings in Chapter 4 may have some limitations in relation to the cases investigated, since their level of organisational maturity in BIM implementation varies. Despite the fact that the study adopted a multi-case research strategy, the aim was not to generalise, but to test a comparison between asset owners from different sectors and to demonstrate how business needs influence the content of operational information requirements, which in turn, impacts on business value in the long run. Furthermore, the findings of this study have to be seen in light of some limitations. The corporate structure of each organisation sampled for this study holds important contextual differences. The primary business focus of each organisation highlighted differences in the level of detail of items under the Object Category classification. It is evident that Company A had developed a detailed list of MEP related items in comparison to Companies B and C. Also, it is obvious that Company C had a more holistic view towards the development of the operational information requirements in relation to the overall building envelope when compared to

Companies A and B. These contextual differences hindered the ability to conduct a like for like comparison of the operational information requirement templates. Also, due to the fact that asset owners are not a homogeneous organised group of organisations, and even similar asset owners performing the same business functions and competing in the same market may have different methods of performing the same task, as such, a like for like comparison may never be possible.

The research questions in Chapter 4 focused on evaluating operational information requirements and how they related to BIM. The study answered the research questions by identifying the common BIM-based operational information requirements across three case studies. Also, it contributed to the overall research question by helping to identify the *Core* element and *Requisition* sub-element of the BIMAsset VRM. Moreover, the data analysis revealed that very few information requirements are shared across the three cases. This is due to the nature of the cases investigated, the business sector, information requirement development strategy and BIM data perspective. Company A as a MEP sector stakeholder was able to develop a detailed list due to the specialised nature of its operations. On the other hand, the perspective of Company B focuses on managing a whole facility. Here, the facilities department utilised a strategy of prioritising higher-level specifications for an agile 5% that is critical to their in-house maintenance operations. Also, Company C had a similar perspective of managing the whole facility. They adopted a strategy of pulling data from the building models through linked data, which is facilitated by the BIM office. Hence, the differences emerged in terms of focus and detail amongst the list of operational information requirements for each case investigated.

For most asset owners, the development of operational information requirements is a tricky part of the BIM process, and they require a deep understanding of business information requirements to be able to develop their requirements (Ashworth, Tucker and Druhmann, 2016; Ashworth, Tucker and Druhmann, 2017b). Therefore, the development of understanding for asset owners by highlighting endogenous and exogenous business level factors that impact operational information requirements is an original contribution of this study. Addressing the gap in knowledge by providing guidance to clients for the development of operational information requirements is another original contribution of this study. Also, this study highlighted the link between BIM and AM strategy, which is the development of an operational information requirement template that focuses on business needs whose execution generates business value for the asset owner.

According to Ashworth *et al.* (2016), a clear definition of information needs and requirements is required for the potential business value of BIM to be fully realised. The need for the definition of operational information requirements for the BIM-based process is necessary in order to address the challenges of interoperability, poor information fidelity and data usability, so as to support the lifecycle management of assets (Cavka, Staub-French and Poirier, 2017). Similarly, Ashworth, Tucker and Druhmann (2016) suggested the development a BIM information requirement strategy for the asset owner that helps to define what information is required, in which format it is desired, and when it is needed in the BIM process. The development of information requirements, as well as BIM deliverable templates, is seen as an important benchmark for all project-related performance assessment (Cavka, Staub-French and Poirier, 2017). Moreover, Chapter 4 highlighted three different approaches towards the development of operational information requirements a guide for asset owners to be able to articulate and structure their BIM-based operational information requirements. Although, it should be emphasised that it is crucial to develop operational information requirements for BIM-based processes that are responsive to organisational business needs. However, Cavka, Staub-French and Poirier (2017) highlighted some inconsistency in the terminology and in the way information requirement templates are used and developed. A reason for this is highlighted in this part of the study, and this is because every organisation is unique in its requirements and business operations. As such, this represents a significant contribution to the research outcomes, together with the identification of the *Core* element and *Requisition* sub-element. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Requisition*

9.3 DISCUSSION OF THE FINDINGS OF OBJECTIVE 2

Chapter 5 identified strategies and techniques of how asset owners integrated BIM with AM systems, including the value derived from such integration. The main contribution of this part of the study is the identification of a BIM-AM implementation strategy, systems architecture, data governance procedures, change management strategies, stakeholder management approaches and performance management techniques. This part of the study documented the strategic approach adopted by an asset owner in integrating BIM-AM systems. Apart from the theoretical contributions, the findings in Chapter 5 provided significant guidance to the asset owner in practical strategies for integrating and utilising BIM-AM systems during asset operations.

The findings in Chapter 5 highlighted the importance of *Requisition*, *Policy*, *Strategy* and *Systems Architecture* in the implementation of a BIM-based AM system, and in the development of the BIMAsset VRM. The identification of the *Requisition* sub-element was due to the understanding of the significance of the identifying organisational information needs in Company D. This process is where the asset owner investigated the organisational information requirements from the perspectives of systems, processes, users and data sources. Although, the significance of the *Requisition* sub-element has been identified in Chapter 4, the findings in Chapter 5 reinforced that claim. Furthermore, the findings in Chapter 5 highlighted the importance of adopting the appropriate policy standards for implementing BIM in AM. That is, the utilisation of organisational standards, such as BS:1192 (BSI, 2016), PAS:1192-2 (BSI, 2013), PAS:1192-3 (BSI, 2014a), BS:1192-4 (BSI, 2014b), and PAS:1192-5 (BSI, 2015) by Company D. These aspects informed the inclusion of the *Policy* sub-element during the development of the BIMAsset VRM. In addition, the findings in Chapter 5 demonstrated a unique strategy adopted by the asset owner in integrating BIM-AM systems during asset operations. That is, the BIM implementation plan, implementation strategy and value realisation plan. These aspects informed the inclusion of the *Strategy* sub-element during the development of the BIMAsset VRM. Moreover, the findings in Chapter 5 highlighted the significance of planning and implementation of an adaptable systems architecture that streamlined BIM-AM systems for effective execution of AM tasks. This demonstrated how BIM, AM and FM systems, including how other DITs could be integrated in a unique framework. These findings informed the inclusion of the *Systems Architecture* sub-element during the development of the BIMAsset VRM. The identification of the aforementioned factors related to the development of the BIMAsset VRM; including how the findings of this objective contributed to addressing the broader research aim of developing a model for asset owners to realise the business value of BIM implementation in an AM system in the lifecycle of assets.

The single case study strategy adopted in Chapter 5 covered strategic aspects of implementing BIM in AM. This investigation was carried out in a large retail asset owner. Therefore, it is acknowledged that there could be bias in relation to the findings, and the applicability of the results to other asset owners from different sectors. Although the aim is not to generalise the findings, the findings helped to develop understanding and provided guidance to asset owners aiming to implement BIM in AM.

The research question in Chapter 5 focused on investigating effective approaches for streamlining BIM-AM systems and the business value of such integration. This part of the study answered the research question by identifying the techniques and strategies for integrating BIM-AM systems, including what information should be captured from physical assets towards BIM-based integration. Similarly, it contributed to the overall research question by helping to identify the *Core* element and *Requisition*, *Policy*, *Strategy* and *Systems Architecture* sub-elements of the BIMAsset VRM. Moreover, the data analysis highlighted the significance for asset owners to: (a) develop for a clear strategy prior to BIM adoption; (b) connect the strategy to the business goals; (c) the discovery of organisational information needs in relation to business processes; to be able to develop an effective BIM-based AM strategy.

Ashworth, Tucker and Druhmann (2016) highlighted the need for asset owners to develop employers, organisational and asset information requirement strategies that are based on a robust understanding of BIM standards, guidelines and tools. As suggested in Chapter 5, the organisational approach towards the documentation of information requirements and its relationship to the AM strategy is important. Also, one of the challenges of utilising BIM in the operations and use phase is for the asset owner to identify by whom, how and when the data should be provided throughout the asset lifecycle (Becerik-Gerber *et al.*, 2012). This barrier prevents the capture of the full value of BIM across asset lifecycles (Cavka, Staub-French and Poirier, 2017). Therefore, Chapter 5 highlighted the significance of having an established process that was utilised by the case study in identifying suitable data systems, processes, users and sources. This represented a key activities required for an asset owner to be able to organise the documentation of organisational needs in relation to their AM strategy. The results in Chapter 5 (Objective 2) differ from that of Chapter 4 (Objective 1) because in the former, the findings highlighted strategies of probing and identifying information needs; whereas, that of the latter provided strategies of structuring the information requirements in a presentable manner. Furthermore, as identified in the previous chapter, the findings in this chapter reinforced the inclusion of the *Core* element and *Requisition* sub-element. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Requisition*

BIM implementation requires more than just the uptake of technology but a whole business process change (Eastman *et al.*, 2011). BIM is a disruptive technology that has required the development of new standards and policy documents in order to attain smooth implementation in the AEC industry (Kassem *et al.*, 2014). Succar (2009) highlighted that policies are written principles or rules to guide decision-making during BIM implementation. Similarly, Guillen *et al.* (2016) suggested the use of policy documents for implementing BIM in AM. This is because, the need for protocols and standards impact on the rate of increase in adoption, consistency of implementation and value realisation of BIM in the asset lifecycle. Therefore, the findings in Chapter 5 highlighted key policy documents utilised by the case study in developing a methodological approach towards BIM implementation in the operations and use phase (BSI, 2013; BSI, 2014a; BSI, 2014b; BSI, 2015; BSI, 2016). These policy documents play a pivotal role in preparatory, regulatory and contractual activities throughout the asset lifecycle (Kassem *et al.*, 2014). Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Policy*

Eastman *et al.* (2011) highlighted the need to develop robust organisational strategies for BIM implementation. Also, underlining that organisations should not adopt new technologies without performing proper planning and feasibility studies. This part of the study highlighted the development of a four-part strategy aimed at facilitating smooth workflow during BIM-AM implementation. The business value of BIM implementation for asset owners are seen to include: integration of AM systems, data, operational and facility management, including whole lifecycle AM (Love *et al.*, 2014). As such, the decision by an asset owner to adopt BIM in AM can enable strategic business outcomes (Love *et al.*, 2013). However, a robust business strategy is necessary to harmonise business outcomes and BIM-based process deliverables and to ensure harmony between both. The research outcomes of Objective 2 showed that the case study has succeeded in the development of a BIM-AM strategy by taking into account all aspects of business needs and organisational processes in order to ensure that value is derived from BIM adoption. The case study has developed a four-part BIM-AM strategy that incorporates the selection of the right technological systems, implementation of business process engineering around new protocols, the definition of new data structures, and a focus on organisational culture and training. In developing the BIM-AM strategy, the case study conducted five activities that investigated organisational systems, processes, users and data sources. The five critical tasks are: Desktop Discovery, Stakeholder Engagement, Stakeholder Discovery, Stakeholder Workshops and Technical and Data Source Discovery. These activities helped the case study to develop a robust BIM-AM strategy. Barlish and Sullivan (2012) argued that the barriers that hinder the realisation of BIM business value are as a result of: organisational changes due to of new systems, diverse stakeholders, resistance to change by users, and improper utilisation of systems. As such, this part of the study highlighted how the case study utilised the four cornerstones of BIM implementation (governance, change, stakeholder and performace management) in order to overcome these challenges. On the other hand, Love *et al.* (2013) suggested that many asset owners do not prepare a value delivery plan when considering an investment in BIM. However, the case study highlighted the development of three key stages for BIM adoption in the asset lifecycle. These are the strategic phase, implementation phase and value realisation phase. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Strategy*

Interoperability between systems, software and organisations serves as a major barrier to BIM adoption and subsequent value realisation in the lifecycle of assets (Becerik-Gerber *et al.*, 2012; Love *et al.*, 2014). As such, it is important for asset owners to develop and implement effective strategies to overcome interoperability issues in BIM implementation in the operations and use phase. This is because, without smooth interoperability between technological systems and software, the asset owner may not be able to realise BIM business value in asset operations. The results in this part of the study highlighted the consciousness of the case study in the development of suitable approaches for overcoming interoperability issues by analysing the properties and functionalities of each system, and how it contributes to the overall BIM-AM strategy. Similarly, Brous, Herder and Janssen (2016) suggested that data infrastructure that produces trusted data enables asset owners with the capability to make the right decisions. As such, in the case study, systems architecture and data governance enabled a framework for the right use of data within the organisation leading to standardisation, alignment and compliance with organisational objectives. The research results of Objective 2 highlighted the novel design of a systems architecture in the case study, with a variety of platforms for executing the multifarious BIM-AM business processes. Furthermore, Koronios, Lin and Gao (2005) argued that in order for asset owners to derive the full business value of assets, they need to be managed in an effective and efficient way. This involves the development of system and data infrastructures with robust data management protocols and processes. (Bosch, Volker and Koutamanis, 2015). On the other hand, since BIM implementation involves dramatic changes in the current technological systems and business practices, Mihindu and Arayici (2008) highlighted the preparation, roll-out and post-implementation phases as key stages of development for implementing BIM-based processes. Similarly, the results from this part of the study show that the case study had been successful in incorporating social aspects as part of the activities in the integration of BIM-AM systems. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Systems Architecture*

9.4 DISCUSSION OF THE FINDINGS OF OBJECTIVE 3

Chapter 6 investigated key techniques of managing asset data and how information content collected from built assets generated business value in a BIM-based Asset Information Management (AInfM) system. The main contributions of this part of the study is the identification of organisational data management levels (operational, tactical and strategic), data analysis levels (data point, space, zone, floor, building and portfolio), data reporting processes, data formats and sources, typologies of BIM business value and challenges of deriving BIM business value in AM. The key contribution of this part of the study is in demonstrating that value could be derived from the effective management of information assets within an organisation through BIM. The effective management of information assets was carried out through a systematic method of defining data requirements, managing data collection and transfer, and efficient reporting of asset data through an AInfM system. Apart from the theoretical contributions, the findings of Chapter 6 provided significant guidance for the asset owner in relation to practical strategies for managing asset data and how asset information is collected, organised, stored, controlled, analysed, secured, shared and reported within a virtual AIM system for strategic management-based decisions.

The findings in Chapter 6 underscored three significant factors in relation to the development of the BIMAsset VRM: The first is, the typologies of BIM business value, and the second is, the need to qualify the identified values. While the third is the need to identify and utilise outputs of the system. The first aspect informed the inclusion of the *Drivers* element and the two sub-elements: *Tangible Value* and *Intangible Value* in the BIMAsset VRM. The findings in Chapter 6 highlighted the significance of defining the nature of any value identified from the observed outcomes in a BIM-based AM system, which could be either tangible or intangible. These should be defined prior to measurement. The identified values (management, commerce, efficiency, industry, user and technology value) were incorporated into the BIMAsset VRM Flowchart in the result evaluation task. Similarly, the second aspect informed the inclusion of the *Input* element of the BIMAsset VRM. The findings highlight the type of data or information required by the BIM-based AM system. The identification of static and dynamic information types is a significant contribution to this effect. Also, the third aspect informed the inclusion of the *Output* element of the BIMAsset VRM. The findings highlighted management and operational KPIs as outcomes of the BIM-based AM process. The identification of these factors related to the development of the BIMAsset VRM; including how the findings of this objective contributed to addressing the broader research aim of developing a model for clients to realise the business value of BIM implementation in an AM system in the lifecycle of assets.

Chapter 6 adopted a single case study approach in identifying strategic approaches of AInfM in BIM-based AM systems. As such, the processes identified in Chapter 6 are unique to Company A. Therefore, it is acknowledged that there could be limitations in transferring the same approaches to other asset owners. Even though the study does not aim to generalise the findings, the findings may provide practical guidance to asset owners aiming to implement BIM in AM.

The research question in Chapter 6 focused on investigating techniques of efficiently managing asset data of built assets through BIM, and how value can be derived from the process. The study answered the research question by demonstrating how the information content captured from built assets generated business value in AM. It also addressed the research question by presenting value typologies that effective AInfM could yield for the asset owner: management, commerce, efficiency, industry, user and technology value. Similarly, it contributed to the overall research question by helping to identify the *Drivers*, *Input* and *Output* elements of the BIMAsset VRM. Moreover, the present study adds to the existing literature by highlighting the potential for asset owners to obtain business value from BIM-based initiatives during asset operations. The study helps to develop the understanding of asset owners, as they are unaware of the management and operational benefits of BIM-based AInfM in the operations and use phase (Love *et al.*, 2014). Also, issues surrounding AInfM for asset owners such as strategy, information requirements, reporting process, business value and challenges have been addressed in this study. The study identified: (a) the elusive value of information, (b) lack of understanding of BIM-based AInfM implementation, (c) and technical and operational challenges of BIM-based AInfM as reasons for such lack of awareness.

A significant purpose of BIM implementation by asset owners is the potential to enhance the performance and productivity of built assets throughout their lifecycle (Love *et al.*, 2013). Vass and Karrbom Gustavsson (2014b) emphasised the need for asset owners to be aware of the prerequisites required to enable the positive effects of BIM. In this respect, the research outcomes in this part of the study highlighted three stages of management: operational, tactical and strategic. Also, this part of the study provided systematic techniques for data analysis, data reporting processes, data formats and sources. On the other hand, asset owners are unsure of the business value of BIM and are becoming increasingly interested in its economic effects on their assets. As such, this has become a primary strategic concern for asset owners (Vass and Karrbom Gustavsson, 2014b). In this part of the study, the case study demonstrated the use of BIM through effective AInfM, its economic value to the asset owner, and the types of business values that could be derived. Certainly, the exposure of BIM business value would in turn enhance its adoption in the AEC industry (Barlish and Sullivan, 2012). The case study revealed that effective AInfM through BIM had positive effects on the generation of business value for the asset owner. Also, the case study demonstrated how the asset owner quantified BIM business value within organisational processes and outcomes. Primarily, this part of the study highlighted types of BIM business value in the operations and use phase that are tangible in nature. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Drivers	*Tangible Value*

Barlish and Sullivan (2012) suggested that the value of BIM consists of tangible and intangible outcomes. This part of the study highlights intangible outcomes that enable positive effects for the asset owner. Similarly, some authors highlighted examples of intangible BIM business value in asset operations such as improved productivity, better risk management, regulatory compliance and competitive advantage (Barlish and Sullivan, 2012; Love *et al.*, 2013; Love *et al.*, 2014). Therefore, these type of business values alongside tangible ones need to be acknowledged by asset owners. The research outcomes of this objective demonstrated how the asset owner attempted to measure intangible BIM business value within BIM-based processes through inference on operational outcomes. This was done through different types of analyses by evaluating results from IoT sensors, BMS and the like. In essence, this part of the study highlighted types of BIM business value in the operations and use phase that are intangible in nature. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Drivers	*Intangible Value*

The information component in BIM refers to data that is relevant within the context of its application (Parsanezhad and Dimyadi, 2014). In other words, this refers to data that is qualitative and valuable to the asset owner to execute BIM-based processes. This part of the study highlighted data transactions in executing BIM-based processes such as: input, tasks and output. The research outcome in this part of the study highlighted inputs such as: all building information models, asset information models, project information models, associated links, COBie, asset information and maintenance information. These sets of information may be static or dynamic. Also, they may be from the design and construction phases or preceding AM activities. Similarly, Pishdad-Bozorgi *et al.* (2018) suggested the use of information management frameworks such as the Industry Foundation Classes (IFC) and Construction Operations Building information exchange (COBie) files including associated links to execute BIM-based tasks in asset operations. Furthermore, CMMS are deployed to support the execution of BIM-based processes for AM in order to efficiently manage asset and maintenance information (Parsanezhad and Dimyadi, 2014). Also, PAS1192-3 (BSI, 2014a) highlighted the delivery of structured data through project information models and asset information models. Essentially, this part of the study highlighted the inputs involved in order to execute BIM-based processes efficiently during asset operations. Therefore, the following element and sub-elements are proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Input	*Information Models*
Input	*COBie*
Input	*IFC*
Input	*Links*
Input	*Asset Information*
Input	*Maintenance Information*

Generally, business processes such as organisational and operational management functions will be affected by BIM adoption. As such, Barlish and Sullivan (2012) suggested that these changes should be analysed in order to observe the outcomes of BIM-based processes. This part of the study highlighted the data transactions associated with executing BIM-based processes: input, tasks and output. This part of the research proposed that the outcomes that contain BIM business value are the management and operational maintenance KPIs. This is emphasised by highlighting the information management levels (operational, tactical and strategic) and how data is reported for strategic decision-making. Similarly, Zuppa, Issa and Suerman (2009) suggested that BIM-based outcomes are commonly measured through KPIs. This is because KPIs provided internal and external BIM-based operational asset data with measurable results to validate them (Cox, Issa and Ahrens, 2003; Barlish and Sullivan, 2012). The research outcome in this part of the study demonstrated the observation and evaluation of management and operational KPIs with measurable results. This showed that the case study had succeeded in the effective implementation of AInfM. In general, this part of the study highlighted the organisational and operational management functions that contain BIM business value. Therefore, the following element and sub-elements are proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Output	*Management KPIs*
Output	*Operational Maintenance KPIs*

9.5 DISCUSSION OF THE FINDINGS OF OBJECTIVE 4

Chapter 7 identified key BIM-based AM processes (activity systems) that drive business value in asset operations, and how they related to maturity. The main contribution of this part of the study is the identification of six activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management) that drive BIM business value in AM. Another contribution of this part of the study is the maturity appraisal of four large asset owners in relation to their tendency of realising BIM business value. Apart from the theoretical contributions, the findings of Chapter 7 provided significant guidance to the asset owner on the crucial business processes that drive business value in a BIM-based AM system, and how their maturity could be appraised.

The findings in Chapter 7 highlighted the importance of understanding the key business processes that drive BIM business value for the asset owner. Also, it highlighted the importance of the BIM governance elements that influenced BIM implementation in AM; and this informed the inclusion of the *Influencers* element, and *People*, *Process* and *Technology* sub-elements during the development of the BIMAsset VRM. Moreover, Chapter 7 contributed to the operability of the BIM-based AM system by informing further development of the BIMAsset VRM flowchart. This part of the study highlighted the key tasks to be performed by the BIM-based AM system by providing more details on the key business processes that drive BIM business value. The identification of these factors related to the development of the BIMAsset VRM; including how the findings of this objective contributed to addressing the broader research aim of developing a model for clients to realise the business value of BIM implementation in an AM system in the lifecycle of assets.

The multi-case study carried out in Chapter 7 covered asset owners that operate their facilities within four sectors; Health, Education, Retail and Government (mixed-use). These results must be interpreted with caution, and a number of limitations should be borne in mind. Hence, it is acknowledged that the results could be biased towards certain sectors of the AEC industry or the four investigated asset owner types. The organisations investigated in this study hold contextual differences in relation to BIM adoption strategies and business process maturity. The researcher observed the different time scales and experiences in terms of BIM implementation within the sampled asset owners. These factors led to varying levels of organisational understanding of BIM, maturity of BIM-based processes and change management approaches. Hence, the contextual limitations in the ability to conduct a like for like comparison for the identified BIM-based processes within asset owners that drive BIM business value. Although a multi-case research strategy was adopted, the aim of this is not to generalise but to compare the level of development of the business processes within asset owners from different sectors and the business value derived by them.

The research question in Chapter 7 focused on investigating the key business activities that drive BIM business value in AM. This part of the study addressed the research question by identifying the vital business activities that drive BIM business value in AM: BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management. This part of the study also addressed the research question by demonstrating how realising BIM business value related to organisational business process maturity. Similarly, it contributed to the overall research question by helping to identify the *Influencers* element and to highlight the Tasks aspect in the BIMAsset VRM Flowchart. Moreover, the present study adds to existing knowledge by emphasising that the capability of asset owners to derive business value of BIM in AM has implementation and maturity undertones. From the data analysis, it was deduced that the maturity of the activity systems impact on the ability of an asset owner to realise BIM business value. The results showed that proactive management of the six activity systems could help develop organisational BIM maturity in order to realise BIM business value. Furthermore, the research found that asset owners across four sectors (Health, Education, Retail and Government) placed more emphasis on the activity system of maintenance management. Also, the activity system with the least emphasis was contracts management. Furthermore, the most developed BIM governance dimension was the Process dimension, whereas the People dimension was the least developed. The study showed that the most mature organisations have defined processes of value realisation management.

The development of a robust BIM governance model is key to overcoming BIM adoption challenges in the AEC industry (Rezgui, Beach and Rana, 2013). This is because there is a requirement for synergy between key governance instruments during BIM implementation in order for asset owners to derive the desired positive effects. Similarly, Bosch, Volker and Koutamanis (2015) highlighted the lack of alignment between people, processes and systems as a major factor for the marginal BIM business value realised by asset owners. Therefore, for progress to be made in this subject area, a fundamental change is needed in the way asset owners manage BIM implementation and develop organisational BIM maturity. This is because of the inability of asset owners to assimilate and apply BIM may result in missed opportunities and lack of sustainability in achieving business value (Love *et al.*, 2013). However, this part of the study highlighted three key BIM governance dimensions that asset owners should pay attention to: People, Process and Technology. Similarly, other studies acknowledged the influence of people, process and technology on BIM adoption and the execution of BIM-based processes (Bosch, Volker and Koutamanis, 2015; Prodan, Prodan and Purcarea, 2015; Alreshidi, Mourshed and Rezgui, 2017). Also, this part of the study identified six important AM activities in relation to BIM business value realisation and how they can be appraised from the perspective of people, process and technology. Similarly, Bosch, Volker and Koutamanis (2015) adopted people, process and technology as units of analysis for factors that influence BIM adoption. Fundamentally, this part of the study highlighted the key instruments that influence BIM implementation during asset operations and key business processes that drive BIM business value. Therefore, the following element and sub-elements are proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Influencers	*People*
Influencers	*Process*
Influencers	*Technology*

9.6 DISCUSSION OF THE FINDINGS OF OBJECTIVE 5

Chapter 8 identified the techniques and strategies of measuring BIM business value in AM processes, including how intangible value could be conceptualised. The main contribution of this part of the study is the development of a four-stage value realisation process for tangible and intangible value. Also, the study made significant contributions by presenting a unique methodology for conceptualising intangible value and linking it to tangible value for measurement. A further contribution of this part of the study was the development of the BIMAsset Maturity Model, which was a practical model for asset owners to appraise their organisation in relation to their tendency of realisation of BIM business value.

The findings in this part of the study highlighted a four-step methodology for evaluating BIM business value during asset operations. Observe, assess, measure and value (tangible value); and observe, link, measure and value (intangible value). This informed the inclusion of the *Drivers* element, including *Tangible Value* and *Intangible Value* sub-elements in the BIMAsset VRM. Although the significance of these factors had been identified in Chapter 6, the findings in Chapter 8 reinforced that claim. Chapter 6 identified the typologies of BIM business value and Chapter 8 develops a four-step evaluation technique for measuring tangible and intangible value. The identification of these factors related to the development of the BIMAsset VRM; including how the findings of this objective contributed to addressing the broader research aim of developing a model for clients to realise the business value of BIM implementation in an AM system in the lifecycle of assets.

Furthermore, the findings of this study have to be seen in light of some limitations. This part of the study developed the four-stage value realisation models for tangible and intangible value through data from the literature review. These are inductively analysed to develop a unique framework that aimed to assist the asset owner in evaluating BIM business value. Furthermore, the findings presented in this part of the study are conceptual and have not been tested in real-life use cases.

The research question in Chapter 8 focused on investigating techniques of evaluating BIM business value. This part of the study answered the research question by developing value measurement techniques for measuring tangible and intangible value. Also, it provided a framework for linking intangible to tangible value. Also, it developed a maturity model for organisational appraisal in relation to the tendency of realising BIM business value. Furthermore, it contributed to the overall research question by helping to identify the *Drivers* element, including *Tangible* and *Intangible Value* sub-elements of the BIMAsset VRM. Also, the research outcomes contributed to the existing literature by presenting novel techniques for measuring tangible and intangible value as well as a unique approach for conceptualising intangible value.

Love *et al.* (2013) argued that BIM adoption is becoming an integral part of many governments' strategies to derive better value for money from built assets. However, asset owners constantly fail to prepare a value delivery plan when considering BIM implementation. As such, this leads to asset owners not being able to achieve expected business value. This finding highlighted the need for proper planning during BIM implementation prior to value realisation. Furthermore, inadequate and inappropriate appraisals have been identified as significant barriers to BIM business value evaluation (Lin and Pervan, 2001; Lin and Pervan, 2003). This part of the study provided measurement techniques that are suitable to the BIM and AM contexts. Also, it is important for asset owners to observe how business value will materialise during asset operations (Love *et al.*, 2014). As such, the findings in this part of the study presented a four-step methodology for evaluating tangible value. This starts from the first step where the BIM-based outcomes are observed, then they are assessed against pre-set benchmarks, then they are measured, and then the business value is qualified. Moreover, the determination of how and what to measure are is a significant barrier in quantifying BIM business value (Love *et al.*, 2013). As such, the research results in this part of the study suggested value measurement techniques such as ROI, quantitative KPIs, process mapping and savings to investment ratio in order to facilitate the evaluation of BIM-based management and operational outcomes. Essentially, this part of the study highlighted the need to evaluate tangible BIM business value and provided a methodology for achieving that. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Drivers	*Tangible Value*

On the other hand, Love *et al.* (2013) emphasised the necessity for an evaluation approach for BIM business value that goes beyond the traditional boundaries of financial evaluation. As such, this part of the study presented a four-step methodology for evaluating intangible value. This starts from the first step where the BIM-based outcomes are observed, then the outcomes are linked to tangible outcomes and are assessed against pre-set benchmarks, then they are measured and then the business value is qualified. However, Barlish and Sullivan (2012) argued that intangible value is difficult to quantify, and its assessment is prone to subjectivity and estimation. As such, the results in this part of the study merely argued the need for conceptualising intangible value and proposes a model for its actualisation. Furthermore, Vass and Karrbom Gustavsson (2014b) highlighted economic benefit indicators anchored at the operational level for effective asset data utilisation and internal benchmarking. Similarly, this part of the study suggested qualitative measures to help account for intangible BIM business value during asset operations. Also, the research outcomes of this objective proposed a value linkage model for conceptualising and evaluating intangible value through these qualitative measures. In general, this part of the study highlighted the need to evaluate intangible BIM business value and provided a methodology for achieving that. Therefore, the following element and sub-element is proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Drivers	*Intangible Value*

Alreshidi, Mourshed and Rezgui (2017) highlighted the need for data to be managed effectively in order to govern the BIM process productively. This is because BIM utilisation in the operations and use phase has changed the traditional methods of asset documentation, control and analysis (Kiviniemi and Codinhoto, 2014). However, effective data governance practices are important because they affect the availability, integrity and security of data used within the organisation (Alreshidi, Mourshed and Rezgui, 2017). This part of the study highlighted that real-time data from BIM greatly improves the operability of built assets for the asset owner. Similarly, Davtalab (2017) suggested timesaving benefits related to the use of real-time data during asset operations. Also, Khaja, Seo and McArthur (2016) suggested the potential applications of a BIM capable CDE for sustainable data management and transfer during asset operations. In the same vein, this part of the study underscored the requirement of utilising a CDE for data management tasks and information transactions for BIM-based AM processes. On the other hand, data security is a major concern for BIM adoption (Alreshidi, Mourshed and Rezgui, 2017). As such, this part of the study emphasised the necessity for asset owners to make appropriate provisions for data security within their data management operations. It guided asset owners on how to approach data security concerns by highlighting key policy documents. Fundamentally, this part of the study highlighted the key factors that relate to good data management and fidelity during asset operations. Therefore, the following element and sub-elements are proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Core	*Real-time Data Update*
Core	*Data Security*
Core	*BIMAsset CDE*

Love *et al.* (2014) argued that all BIM projects have outcomes, but not all outcomes are benefits. This is because there needs to be an appropriate methodology in place for evaluating BIM business value in an organisation. The research outcome in this part of the study highlighted that BIM-based outcomes could enable business value at different levels within the organisation and at different periods. Hence, the efficacy of a value delivery plan. This is because the process of value management overlaps investment appraisal in the business case (Love *et al.*, 2013). Therefore, this part of the study suggested that BIM business value could be realised at the user, system, business and ecosystem levels. Similarly, Cronk and Fitzgerald (1999) highlighted the business value that is contributed to an organisation is either dependent on system properties, user characteristics and/or business factors. Primarily, this part of the study suggested that in order to derive BIM business value in asset operations, the asset owner needs to have a value delivery plan that would indicate: what type of benefit is expected; at what level within the organisation the business value is expected to be delivered; and at what periods. Therefore, the following element and sub-elements are proposed for the BIMAsset VRM:

ELEMENT	SUB-ELEMENT
Business Value Realisation Dimension	*User*
Business Value Realisation Dimension	*System*
Business Value Realisation Dimension	*Business*
Business Value Realisation Dimension	*Ecosystem*

9.7 DISCUSSION OF THE FINDINGS OF OBJECTIVE 6

Chapter 8 included all the findings in Objectives 1-5 and served as the synthesis of results for the whole study. It developed a model for business value realisation of BIM implementation in the lifecycle management of built assets for clients. The main contribution of this part of the study is the development of the BIMAsset VRM, which is the main aim of the whole study. As a model development chapter, this part of the study brought together the elements and sub-elements of the BIMAsset VRM identified in:

- Objective 1 (**Core** – Requisition);
- Objective 2 (**Core** – Requisition, Policy, Strategy and Systems Architecture);
- Objective 3 (**Drivers** –Tangible Value, Intangible Value; **Input** – all building information models, asset information models, project information models, associated links, COBie, asset information and maintenance information; **Output** – Management and Operational Maintenance KPIs)
- Objective 4 (**Influencers** – People, Process and Technology)
- Objective 5 (**Drivers** –Tangible Value, Intangible Value; Core – Real-time Data Update, Data Security and BIMAsset CDE); **Business Value Realisation** – User, System, Business and Ecosystem)

Thus, by synthesising the findings from Chapters 4-8, the model was presented and discussed, including its practical implications to asset owners.

The findings in this part of the study demonstrated the potential of the BIMAsset VRM to support the asset owner in: (a) the definition of key requirements for AM processes; (b) the identification of organisation set-up for effective AInfM; (c) the establishment of metrics for tracking, managing and measuring BIM business value; and (d) the maturity appraisal for asset owners in relation to BIM business value realisation. This part of the study described how the BIMAsset VRM could be used as a guide for asset owners to be able to derive BIM business value in asset operations. In terms of practical application, six different elements have been established, each with a description of characteristics and processes. These elements were developed and discussed in order to enable the applicability of the proposed model. Furthermore, the BIMAsset VRM Flowchart was presented and discussed to demonstrate the practical steps required to implement the BIMAsset VRM by an asset owner. Generally, the adoption of the proposed approach is expected to provide asset managers with effective ways of realising BIM business value in the operations and use phase of built assets. Moreover, the BIMAsset VRM through the BAMM goes on to suggest that there is BIM business value not only within the organisational domain of the asset owner but in the whole AEC ecosystem through key supply chain relationships and platform economies as a result of integrated business models. It is premised that owner-operator organisations with low-value realisation maturity tend to waste more resources in asset operations than organisations with high-value realisation maturity. Mainly, this part of the study presented the opportunity provided by the BIMAsset VRM to enhance the productivity of the asset manager and the business value of built assets.

This part of the study answered the primary research question of how the BIMAsset VRM supports asset managers in deriving BIM business value by developing and discussing the application of the model. Similarly, Serra and Kunc (2015) suggested that value realisation management enabled increased effectiveness of project and strategic governance for organisations. This assertion showed that the evaluation of business value alongside value planning is essential in implementing business strategies. Also, value delivery requires the development and execution of conscious and effective integrated processes because built assets comprise of many systems which are integrated (Fadeyi, 2017). As such, the BIMAsset VRM presented in this study, integrated many different socio-technical systems arranged in elements and sub-elements in order to facilitate effective value management and delivery during asset operations. Similarly, Love *et al.* (2014) argued that value realisation management recognises that technology alone cannot deliver business outcomes, and that business change is required in order for asset owners to achieve their desired and expected results. As such, the BIMAsset VRM was presented as a guide to asset owners in Chapter 8. Furthermore, since BIM implementation could potentially impact the value proposition of asset owners (Love *et al.*, 2014), the study presented a value realisation model that could enable asset owners to realise BIM business value in order to meet wider organisational objectives. This point highlighted the need for value realisation planning alongside monitoring of BIM-based outcomes, value measurement and value qualification. The rationale for the integration of BIM and AM was to ensure that asset owners obtain the results that they expect (Guillen *et al.*, 2016). Consequently, this study presented that without asset owners being able to set and achieve clear targets for BIM business value, its widespread implementation will continue to be a challenge. Thus, a gap in knowledge that the proposed value realisation model in this study filled, that is: (1) addressing measurement of tangible and intangible value; (2) focusing on key business activity systems in asset management; (3) the different types of outcomes to be expected from the BIM-based AM system; (4) typologies of BIM business value; (5) development of the BAMM to appraise capability in relation BIM business value; and (6) application areas of the BIMAsset VRM in AM. Therefore, the following elements and sub-elements are collated and synthesised for the BIMAsset VRM:

Table 9.1: BIMAsset VRM Elements and Sub-Elements

BIMASSET VALUE REALISATION MODEL	
ELEMENT	SUB-ELEMENT
Influencers	*People*
	Process
	Technology
Input	*Information Models*
	COBie
	IFC
	Links
	Asset Information
	Maintenance Information
Core	*Requisition*
	Policy
	Strategy
	Systems Architecture
	Real-time Data Update
	Data Security
	BIMAsset CDE
Output	*Management KPIs*
	Operational Maintenance KPIs
Drivers	*Tangible Value*
	Intangible Value
Business Value Realisation Dimension	*User*
	System
	Business
	Ecosystem

9.8 CHAPTER SUMMARY

This chapter presents the discussion of the contextual findings of the thesis result chapters and how they contributed to the overall study aim. For Objective 1, Chapter 4 found that very few information requirements are shared across the three cases and provided a practical template to guide asset owners for structuring their operational information requirements. Also, it contributed to the overall research question by helping to identify the *Core* element and *Requisition* sub-element of the BIMAsset VRM. For Objective 2, Chapter 5 identified techniques and strategies for integrating BIM-AM systems. Similarly, it contributed to the overall research question by helping to identify the *Core* element, including the *Requisition*, *Policy*, *Strategy* and *Systems Architecture* sub-elements of the BIMAsset VRM. For Objective 3, Chapter 6 demonstrated how the information content captured from built assets generated business value in AM, including the typologies of BIM business value (management, commerce, efficiency, industry, user and technology value). Also, it contributed to the overall research question by helping to identify the *Drivers*, *Input* and *Output* elements of the BIMAsset VRM. It also identified *Tangible Value*, *Intangible Value*, *All Building Information Models*, *Asset Information Models*, P*roject Information Models*, *Associated Links*, *COBie*, *Asset Information*, *Maintenance Information*, *Management KPI* and *Operational Maintenance KPI* sub-elements of the BIMAsset VRM. For Objective 4, Chapter 7 identified the vital business activities (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management) that drive BIM business value in AM and their relationship to business process maturity. Also, it contributed to the overall research question by helping to identify the *Influencers* element of the BIMAsset VRM. For Objective 5, Chapter 8 developed a four-step value realisation methodology for both tangible and intangible value. Also, it contributed to the overall research question by developing the *Drivers* element and the *Tangible* and *Intangible Value* sub-elements of the BIMAsset VRM. For Objective 6, Chapter 8 synthesised the findings of Objectives 1-5 and finalised the development of the BIMAsset VRM.

Moreover, Chapter 8 is not without its limitations. It is worth noting that due to the limitations of identifying respondents for this study, the research did not aim to test the BIMAsset VRM in practical use cases. Hence, this aspect has been recommended for future studies. Also, it should be noted that there could be limitations in relation to the application of the BIMAsset VRM to other asset owner types apart from the ones investigated. Lastly, in terms of further steps, the BIMAsset VRM is validated in a focus group, which is covered in the following chapter.

CHAPTER 10

MODEL VALIDATION

UNIVERSITY OF LIVERPOOL

10.0 MODEL VALIDATION

10.1 CHAPTER INTRODUCTION

This chapter presents the validation process of the study. It covers the aim, criteria and activities carried out to ensure the validity of the BIMAsset Value Realisation Model (BIMAsset VRM) and the BIMAsset Maturity Model (BAMM) developed in this study. A focus group in the form of a six-member expert panel is conducted to validate the BIMAsset VRM and BAMM tool.

10.2 VALIDATION CRITERIA

Validation is a research activity that concerns the verification of whether research outcomes are really about what they are indicative of (Saunders, Lewis and Thornhill, 2016). The BIMAsset VRM is validated through a focus group with industry experts (Fischer, 2006; Flick, 2019). The six participants selected for the focus group are industry professionals that utilise BIM during asset operations. Seale (1999) suggests two versions of expert panels; strong and weak versions. The strong version refers to the evaluation by the panel of the final research report, while the weak version refers to the evaluation of an interim account or document. This study adopts the strong version for validation. Furthermore, the study adopts the following criteria for evaluating theories in order to validate the BIMAsset VRM (Proctor and Capaldi, 2006); fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency. Fruitfulness refers to the simplicity through which the model generates predictions. Prudence concerns how few assumptions the model makes. Quantification denotes the extent to which a model quantifies the phenomena. Scope refers to the number of diverse phenomena the model explains. Progressiveness represents whether the predictions by the model are novel and how it leads to progress in understanding within the domain in which it applies. Internal consistency is the extent at which the model is free from internal contradictions, and external consistency is the extent at which assumptions of the model avoid violating assumptions in other theories. The rationale for adopting this criterion is that it is appropriate for evaluating models or frameworks (Proctor and Capaldi, 2006). Also, it covers a wide range of criteria that would help to guide the researcher in assessing the integrity, reliability, consistency and completeness of the proposed models from the expert panel feedback. The feedback is used to refine the model further, and the results are presented in the following sections. The outcome of this phase, together with previous chapters, form the attainment of all research objectives.

10.3 METHOD OF VALIDATION

A focus group in the form of a six-member expert panel is conducted to validate the BIMAsset VRM and BAMM tool. The validation starts with a 90-minute presentation of the whole thesis. The participants are provided with hard copies of key synopsis and figures of the overall study. A question and answer session is conducted to clarify any aspects of the presentation that are unclear. A 60-minute focus group discussion is facilitated by the researcher discussing the validity of the proposed model in relation to the adopted criteria of: fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency. Furthermore, participants are provided with focus group semi-structured interview questions. The participants are asked to indicate their responses during the focus group discussion on each of the adopted criteria. The participant profile for the expert panel are shown in Table 10.1.

Table 10.1: Focus group respondent profile

S/NO	DESCRIPTION	INDUSTRY ACTOR	EXPERIENCE IN BIM (YEARS)	EXPERIENCE IN AM (YEARS)	EXPERIENCE IN BIM IN AM (YEARS)
1	Participant 1	Consultant	25	10	10
2	Participant 2	Consultant	13	5	5
3	Participant 3	Consultant	10	5	5
4	Participant4	Consultant	5	3	3
5	Participant 5	Consultant	5	1	1
6	Participant 6	Consultant	5	1	1

10.4 RESULTS: VALIDATION OF THE BIMASSET VALUE REALISATION MODEL (BIMASSET VRM)

The results of the BIMAsset VRM validation is presented in the following sections:

10.4.1 FRUITFULNESS

The validation on fruitfulness focuses on evaluating the relevant factors associated with the research problem and how its application improves the current process. In relation to the BIMAsset VRM, the aim of adopting this criterion is to evaluate the application of the model in the process of BIM business value realisation management. Also, it seeks to validate whether the BIMAsset VRM the addresses the relevant factors that could impact on the ability of the asset owner to realise BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BIMAsset VRM, including the management domains of application. The researcher explained aspects covered by the model such as: BIM governance, data and information transactions, organisational strategy, organisational policy, systems architecture and value identification, value measurement, value realisation.

Based on this background and in assessing this validity criterion, the focus group was asked the following question: Does the BIMAsset VRM address relevant factors of the identified problem and could its implementation improve the current process? (Proctor and Capaldi, 2006). One participant replied: *"I think it seems very useful. People are also really interested in tangible benefits and how you can link tangible to intangible"*. Another participant responded: *"In terms of efficiency, yes, because it hit all three of the research problems. Played in the centre of the bullseye, that sort of lacking perceived business value… because a lot of the value of it is multiple perceptible. That is really good for making it tangible in a way that people already understand"*. However, another participant highlighted some concern that: *"In one of our projects… you just keep coming up against the intangibles. And as soon as you go tangible people then start getting really scared, because you are just getting into reducing full time equivalent roles. And then people lose interest because you are just cutting workforce. So even if you can show a time saving in utilising a system,* *the issue then is, what is that person then going to do with their time that is saved. So, in a way by doing that, and just completely splitting the tangible and intangible… And using the links gives some methodology for the least showing it even if you can't still measure it, it becomes a dependency"*. Also, from the interview result sheets, the entire six-member panel agreed that the proposed model addressed relevant factors in relation to the lacking adoption of BIM and BIM business value realisation in asset operations. From these results, the BIMAsset VRM model satisfies the fruitfulness validity criteria.

10.4.2 PRUDENCE

The validation on prudence focuses on assessing the relevant factors associated with the reliability of assumptions made in relation to the research problem. In respect to the BIMAsset VRM, the aim of selecting this criterion is to evaluate the reliability of the model based on the number of assumptions that it takes into account during development. Also, it seeks to validate whether the BIMAsset VRM takes into account little or many assumptions that could influence the ability of the asset owner to utilise it effectively in realising BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BIMAsset VRM, BIM implementation in AM and value realisation management. The researcher explained assumptions made such as: good organisational knowledge of BIM from the perspective of building information management; the notion of value being economic; the model not taking into account existing business processes; good organisational understanding of BIM standards; and reasonable maturity of BIM-based AM processes.

Based on this background and in terms of evaluating this criterion, the focus group was asked the following question: How few are the assumptions that the BIMAsset VRM makes? (Proctor and Capaldi, 2006). One participant responded with scepticism: *"I would say you are assuming that you have in place a strategy"*. Similarly, another participant highlights that "*the model does not consider an initial existing BIM strategy*". Also, from the interview result sheets, four participants agreed that the BIMAsset VRM has made few assumptions, while two participants deemed it made many assumptions. From these results, the BIMAsset VRM model satisfies the prudence validity criteria.

10.4.3 QUANTIFICATION

The validation on quantification focuses on assessing the correctness and integrity of measurements in relation to the research problem. In relation to the BIMAsset VRM, the aim of adopting this criterion is to evaluate the level of coverage for evaluating diverse phenomena during application. Also, it seeks to validate whether the BIMAsset VRM addresses relevant factors that allow for quantification that could impact on the ability of the asset owner to evaluate BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BIMAsset VRM and specifically the measurement of tangible and intangible value. Also, aspects of the framework for linking intangible to tangible value was sufficiently covered. Furthermore, the researcher explained aspects covered by the model such as: the BIMAsset flowchart, types of BIMAsset outcomes, result evaluation and typologies of BIM business value.

Based on this background and in appraising this criterion, the focus group was asked the following question: To what extent does the BIMAsset VRM cover quantification of the identified problem? (Proctor and Capaldi, 2006). One participant responded: *"The linking intangible value to tangible value helps in quantification"*. However, another participant was not sure and retorted: *"It does qualitatively really well. Theoretical but not yet proven… If you're trying to convince leaders in the company to adopt the model, but they have no proof that it works yet."* Also, from the interview results sheets, three participants opined that the BIMAsset VRM covered quantification of the problem, while two participants33% expressed the view that it does not cover the quantification of the identified problem. However, one participant was not sure whether it covers or not. From these results, the BIMAsset VRM model satisfies the quantification validity criteria.

10.4.4 SCOPE

The validation on scope focuses on evaluating the diverse range of topical issues in relation to the research problem covered by the model. In respect to the BIMAsset VRM, the aim of selecting this criterion is to assess the scope of coverage of the research problem in line with the applicability of the proposed solution. Also, it seeks to validate whether the BIMAsset VRM addresses relevant topical issues that could impact on the ability of the asset owner to realise BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements and sub-elements of the BIMAsset VRM, including the BIMAsset VRM flowchart. Also, all the finer details of the BIMAsset Core were sufficiently covered. Furthermore, the researcher explained aspects covered by the model such as: data governance, organisational strategy, information requirements development, input, output, BIM standards, value identification, value linkage, value measurement and value qualification.

Based on this background and in reviewing the BIMAsset VRM in relation to this validity criterion, the focus group was asked the following question: Does the Scope of the BIMAsset VRM cover a reasonable part of the identified problem? (Proctor and Capaldi, 2006). One respondent retorted: *"Yes, it shows multiple path analysis to knowns"*. Similarly, another participant responded: *"Yes, because on an organisational level, this model can be used to understand how an asset has given them value, they can use that same model to understand how the next asset will give them value in the future. So, I'll say yes"*. However, another participant highlighted some concern: *"I thought it did and it was incredibly comprehensive, but my concern is, how would you synthesise all of those aspects of the model as a proposal to an organisation"?* Also, from the interview results sheets, the entire six-member panel was of the opinion that the BIMAsset VRM covered a reasonable part of the identified problem. From these results, the BIMAsset VRM model satisfies the scope validity criteria.

10.4.5 PROGRESSIVENESS

The validation on progressiveness focuses on assessing the novelty of the BIMAsset VRM in relation to the research problem and how its application leads to progress in understanding. In relation to the BIMAsset VRM, the aim of adopting this criterion is to evaluate whether the model is a step in the right direction and whether the theoretical and practical contributions of the model are novel to the domain it applies, which is BIM business value realisation in AM. Also, it seeks to validate whether the BIMAsset VRM improves the understanding of asset owners regarding the complex business process of BIM business value realisation. Here, the researcher ensured that the presentation to the expert panel covered all the elements and sub-elements of the BIMAsset VRM, including the BIMAsset VRM. The researcher explained aspects covered by the model such as: functions of the BIMAsset VRM, intangible to tangible value linkage, value measurement and the BIMAsset VRM flowchart.

Based on this background and with respect to examining this validity criterion, the focus group was asked the following question: Are the predictions of the BIMAsset VRM novel and do they lead to progress in understanding the domain to which it applies? (Proctor and Capaldi, 2006). One participant replied: "*It makes sense, and qualifies the feeling that BIM is the right thing to do*". Similarly, another participant responded: *"Especially useful to encourage BIM uptake as a new business process. It taps into existing processes"*. Also, from the interview results sheets, the entire six-member panel expressed the view that the BIMAsset VRM is novel and leads to progress in understanding within its domain of application. From these results, the BIMAsset VRM model satisfies the progressiveness validity criteria.

10.4.6 INTERNAL CONSISTENCY

The validation of internal consistency focuses on assessing the intrinsic coherence and development of the BIMAsset VRM. In respect to the BIMAsset VRM, the aim of selecting this criterion is to evaluate the level of consistency at which the constituent elements of the model do not contradict one another. Also, it seeks to validate whether this internal consistency or inconsistency could impact on the ability of the asset owner to utilise the BIMAsset VRM in realising BIM business value. Here, the researcher ensured that the presentation to the expert panel covered the interrelationship of all the BIMAsset VRM through the BIMAsset flowchart. The researcher explained the processes of the BIMAsset VRM, starting from input to value realisation, including how all the elements come together as one single model.

Based on this background and in substantiating this validity criterion, the focus group was asked the following question: To what extent is the BIMAsset VRM free from internal contradictions? (Proctor and Capaldi, 2006). One participant responded positively: *"It links terms and concepts that were identified before"*. Similarly, another responds that: *"This may not have internal contradictions but a paradox that the proposed model itself is an intangible value"*. However, another responded with scepticism: *"The model and the flowchart do not show the link between intangible and tangible directly"*. Similarly, another responded that: *"The model does not take into account past experience"*. Also, from the interview results sheets, five participants agreed that the BIMAsset VRM is free from internal contradictions, while one participant opined that it contains some contradictions. From these results, the BIMAsset VRM model satisfies the internal consistency validity criteria.

10.4.7 EXTERNAL CONSISTENCY

The validation of external consistency focuses on assessing the level of contradiction with external theories in relation to the development of the BIMAsset VRM. Regarding the BIMAsset VRM, the aim of selecting this criterion is to evaluate the extrinsic consistency of the concepts proposed by the BIMAsset VRM with other models within the domain of application. Also, it seeks to validate whether this external consistency or inconsistency could impact or influence the ability of the asset owner to utilise the BIMAsset VRM in realising BIM business value. Here, the researcher ensured that the presentation to the expert panel covered examples of other value realisation models such as those proposed by Love *et al.* (2014), Vass (2014a) and Sanchez, Mohamed and Hampson (2016).

Based on this background and in analysing this validity criterion, the focus group was asked the following question: To what extent do the assumptions of the BIMAsset VRM avoid contradicting assumptions in other theories? (Proctor and Capaldi, 2006). One respondent replied: *"No external contradictions, fits well"*. However, another was not sure from the response that: *"In which case, an assumption that this model contradicts is the business concept of quarters and immediate profit and dividing the year up into the profit things, whereas this model does not assume that at all, it assumes an entire lifecycle of an asset, is sort of the whole value in itself, and it should be managed properly, not just within the next three months, within the next year, and in the next five years"*. Furthermore, another participant raised a concern that: *"The model does not talk about aspects around the temporal nature of value realisation, in that, you are not going to realise that value on day 1. So, when in that 75-year period, are you realising that value? What is day 1 value versus day 50 value"*? Also, from the interview results sheets, five participants expressed the view that BIMAsset VRM does not contradict any related external theory, while one participant was of the opinion that it contains some external contradictions. From these results, the BIMAsset VRM model satisfies the external consistency validity criteria.

10.5 RESULTS: VALIDATION OF THE BIMASSET MATURITY MODEL (BAMM)

The BAMM is validated against the following criteria:

10.5.1 FRUITFULNESS

The validation on fruitfulness focuses on evaluating the relevant factors associated with the research problem and how its application improves the current process. In relation to the BAMM, the aim of adopting this criterion is to evaluate the application of the maturity model in the business process of organisational maturity appraisal. Also, it seeks to validate whether the BAMM the addresses the relevant factors that could impact on the ability of the asset owner to appraise organisational maturity in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BAMM, including the management domains of application. The researcher explained aspects covered by the model such as: BIM governance, activity systems, maturity scales, maturity assessment sheets and maturity assessment criteria.

Based on this background and in assessing this validity criterion, the focus group was asked the following question: Does the BAMM address relevant factors of the identified problem and could its implementation improve the current process? (Proctor and Capaldi, 2006). One participant replied: *"It provides clear and specific identification"*. However, another participant responded with some concern that: *"Some terminology makes it a bit unclear"*. Similarly, another retorted: *"This could do with a bit more context"*. Furthermore, from the interview results sheets, the entire six-member panel agreed that the proposed model addressed relevant factors in relation to organisational appraisal and BIM business value realisation in AM. From these results, the BAMM model satisfies the fruitfulness validity criteria.

10.5.2 PRUDENCE

The validation on prudence focuses on assessing the relevant factors associated with the reliability of assumptions made in relation to the research problem. In respect to the BAMM, the aim of selecting this criterion is to evaluate the reliability of the maturity model based on the number of assumptions that it takes into account during development. Also, it seeks to validate whether the BAMM takes into account little or many assumptions that could influence the ability of the asset owner to appraise organisational maturity in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BAMM and assessment criteria. The researcher explained assumptions made such as: good organisational knowledge of BIM from the perspective of building information management; the model not taking into account existing business processes maturity; the allocation of BAMM 1-5 Likert scoring points; and the equal weighting of scores for people, process and technology.

Based on this background and in terms of evaluating this criterion, the focus group was asked the following question: How few are the assumptions that the BAMM makes? (Proctor and Capaldi, 2006). One respondent replied with caution: *"The model assumes sound knowledge of BIM* *definitions"*. Similarly, another respondent retorted that: *"The organisation needs knowledge to self-mark itself in competencies that they may not have"*. Also, another suggested: "The u*se of un-contradictory terms with other BIM concepts"*. Furthermore, from the interview results sheets, five participants agreed that the BAMM had made few assumptions, while one participant deemed it made many assumptions. From these results, the BAMM satisfies the prudence validity criteria.

10.5.3 QUANTIFICATION

The validation on quantification focuses on assessing the correctness and integrity of measurements in relation to the research problem. In relation to the BAMM, the aim of adopting this criterion is to evaluate the level of coverage for evaluating diverse phenomena during application. Also, it seeks to validate whether the BAMM addresses relevant factors that allow for quantification that could impact on the ability of the asset owner to utilise it for organisational maturity appraisal in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BAMM and specifically the maturity assessment sheet. Also, aspects of utilising the maturity model covered in Chapter 7 was sufficiently addressed. Furthermore, the researcher explained aspects covered by the maturity model such as: organisational characteristics to be considered for evaluating the activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management); organisational characteristics to be considered for evaluating the governance dimensions (people, process and technology); and the maturity model appraisal criteria.

Based on this background and in appraising this criterion, the focus group was asked the following question: To what extent does the BAMM cover quantification of the identified problem? (Proctor and Capaldi, 2006). Another participant responded: *"Definitely. I mean, it is a sort of fairly standard way of doing it. It is breaking it down"*. Also, from the interview results sheets, five participants opined that the BAMM covers quantification of the problem, while one participant expressed the view that it does not cover the quantification of the identified problem. From these results, the BAMM model satisfies the quantification validity criteria.

10.5.4 SCOPE

The validation on scope focuses on evaluating the diverse range of topical issues in relation to the research problem covered by the model. In respect to the BAMM, the aim of selecting this criterion is to assess the scope of coverage of the research problem in line with the applicability of the proposed solution. Also, it seeks to validate whether the BAMM addresses relevant topical issues that could impact on the ability of the asset owner to appraise organisational maturity in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered all the elements BAMM including the BAMM appraisal criteria. Also, all the finer details of the BAMM appraisal criteria for all tiers of maturity were sufficiently covered. Furthermore, the researcher explained aspects covered by the maturity model such as: influence of BIM governance dimensions (people, process and technology); the influence of activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management); and organisational characteristics to be considered during maturity appraisal.

Based on this background and in reviewing the BIMAsset VRM in relation to this validity criterion, the focus group was asked the following question: Does the Scope of the BAMM cover a reasonable part of the identified problem? (Proctor and Capaldi, 2006). One respondent replied with scepticism: *"The model does not cover information handover population of systems"*. Another respondent was not sure and replied that: *"The model needs clarity around BIM and AM focus on organisational competence in relation to individuals"*. Also, from the interview results sheets, four participants were of the opinion that the BAMM covers a reasonable part of the identified problem, while one participant was of the view that it does not cover. However, one participant was not sure. From these results, the BAMM model satisfies the scope validity criteria.

10.5.5 PROGRESSIVENESS

The validation on progressiveness focuses on assessing the novelty of the BAMM in relation to the research problem and how its application leads to progress in understanding. In relation to the BAMM, the aim of adopting this criterion is to evaluate whether the maturity model is a step in the right direction and whether the theoretical and practical contributions of the model are novel to the domain it applies, which organisational maturity in relation to BIM business value realisation in AM. Also, it seeks to validate whether the BAMM improves the understanding of asset owners regarding the complex business process of maturity appraisal. Here, the researcher ensured that the presentation to the expert panel covered all the elements of the BAMM, including the tier levels. The researcher explained aspects covered by the model, such as the maturity assessment sheet and maturity appraisal criteria.

Based on this background and with respect to examining this validity criterion, the focus group was asked the following question: Are the predictions of the BAMM novel and do they lead to progress in understanding the domain to which it applies? (Proctor and Capaldi, 2006). One participant answered: *"It uses a standardised methodology for scoring, which is good"*. Similarly, another responded: *"The application of the model is good"*. However, another respondent replied with concern: *"The model is comprehensive, but may be too complex to easily pitch"*. Also, from the interview results sheets, the entire six-member panel expressed the view that the BAMM is novel and leads to progress in understanding within its domain of application. From these results, the BAMM model satisfies the progressiveness validity criteria.

10.5.6 INTERNAL CONSISTENCY

The validation of internal consistency focuses on assessing the intrinsic coherence and development of the BAMM. In respect to the BAMM, the aim of selecting this criterion is to evaluate the level of consistency at which the constituent elements of the maturity model do not contradict one another. Also, it seeks to validate whether this internal consistency or inconsistency could impact or influence the ability of the asset owner to utilise the BAMM for organisational maturity appraisal in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered the interrelationship of all the BAMM elements. That is the BIM governance dimensions (people, process and technology), activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management) and Likert 1-5 scales. The researcher explained the processes of the BAMM with examples of how organisations were appraised as covered in Chapter 7 and how all the elements come together as one single model.

Based on this background and in substantiating this validity criterion, the focus group was asked the following question: To what extent is the BAMM free from internal contradictions? (Proctor and Capaldi, 2006). One respondent replied that: *"Terminology in the model needs knowledge"*. Similarly, another responded: *"When you said self-assessment… it says under level three, integrated product delivery IPD, but what is people's understanding of what those terms mean... Then you need to understand you have to have a good knowledge of this"*. Another responded: "*The model needs clarity that this is for BIM in asset management and not the UK BIM levels"*. Also, from the interview results sheets, the entire six-member panel was of the opinion that the BAMM is free from internal contradictions. From these results, the BAMM model satisfies the internal consistency validity criteria.

10.5.7 EXTERNAL CONSISTENCY

The validation of external consistency focuses on assessing the level of contradiction with external theories in relation to the development of the BAMM. Regarding the BAMM, the aim of selecting this criterion is to evaluate the extrinsic consistency of the concepts proposed by the BAMM with other models within the domain of application. Also, it seeks to validate whether this external consistency or inconsistency could impact or influence the ability of the asset owner to utilise the BAMM for organisational maturity appraisal in relation to BIM business value. Here, the researcher ensured that the presentation to the expert panel covered examples of other maturity models in the AEC industry such as the Bew and Richards (BSI, 2013) maturity model, Succar BIMMI (2010) and SPICE (Sarshar *et al.*, 2000).

Based on this background and in analysing this validity criterion, the focus group was asked the following question: To what extent do the assumptions of the BAMM avoid contradicting assumptions in other theories? (Proctor and Capaldi, 2006). One participant responded with caution that: *"There may be confusion with other BIM measurement models"*. Another suggested the modification of terms by highlighting that: "*Both of you were saying earlier on about the potential confusion of levels this may have with BIM level 2 and other wedges"*. Also, from the interview results sheets, four participants expressed the view that BAMM does not contradict any related external theory, while two participants were of the opinion that it contains some external contradictions. From these results, the BAMM model satisfies the external consistency validity criteria.

10.6 CHAPTER SUMMARY

This chapter focuses on validating of the outcome of the thesis. The BIMAsset VRM is validated through a six-member expert panel in the form of a focus group. The research outcome is validated based on the following criteria: fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency. Furthermore, the validation of the BAMM tool is conducted based on the same criteria. This activity is conducted to ensure that the overall construct of the research outcome is consistent and that variables regarding the phenomenon of BIM value have been sufficiently addressed.

Furthermore, the expert panel made no amendments to the BIMAsset VRM. However, there were comments on the BAMM tool in relation to the stages of maturity. The expert panel expressed the view that the (BAMM 'Levels') should be changed (to BAMM 'Tiers') so as to avoid confusion with other BIM maturity models such as the Bew and Richards (BSI, 2013) maturity model levels and Succar (2010) BIM maturity index levels. Therefore, the BAMM maturity levels were changed from 'Levels' to 'Tiers'. Lastly, the validated models are presented in Figures 10.1 and 10.2:

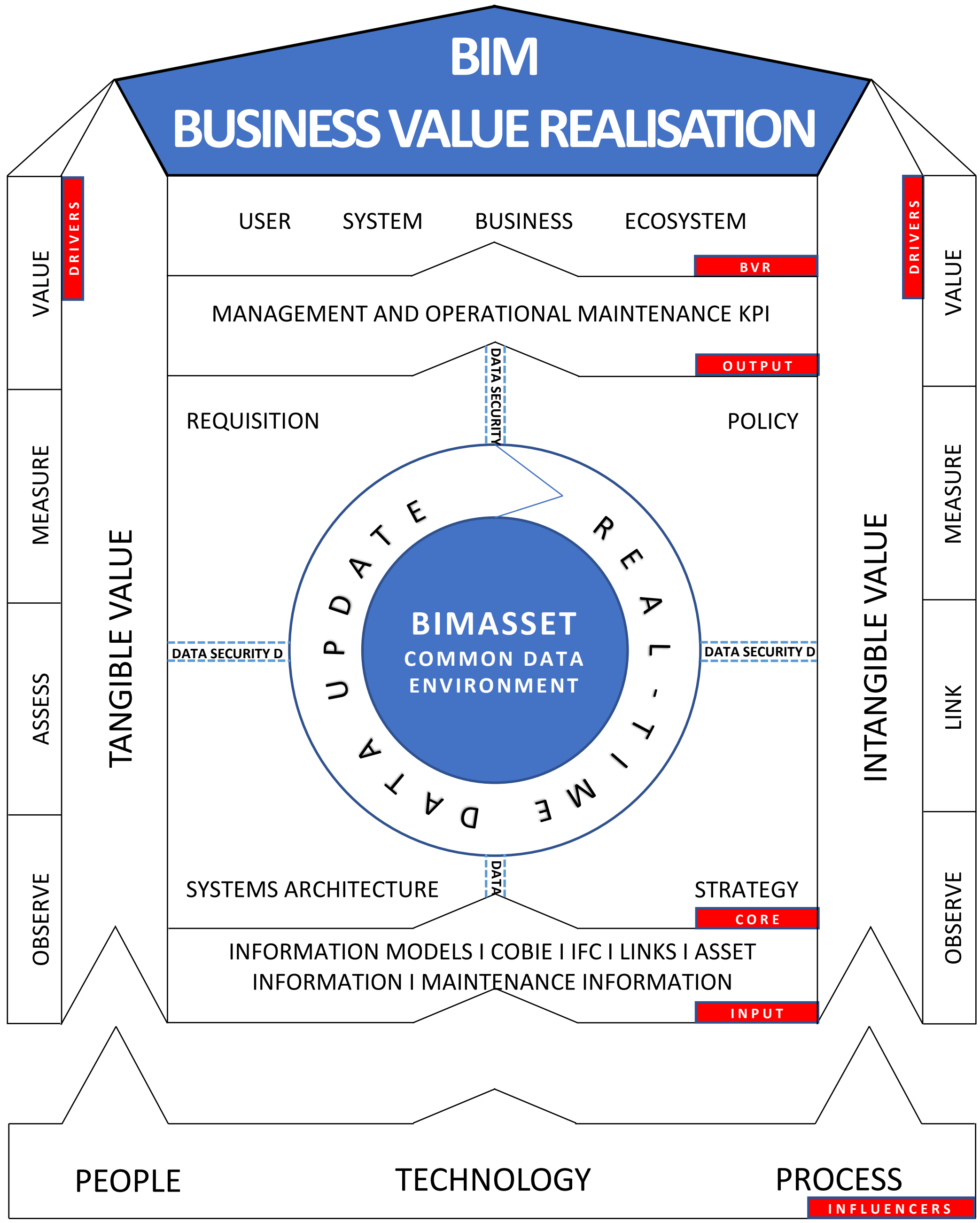


Figure 10.1: Validated BIMAsset Value Realisation Model (BIMAsset VRM)

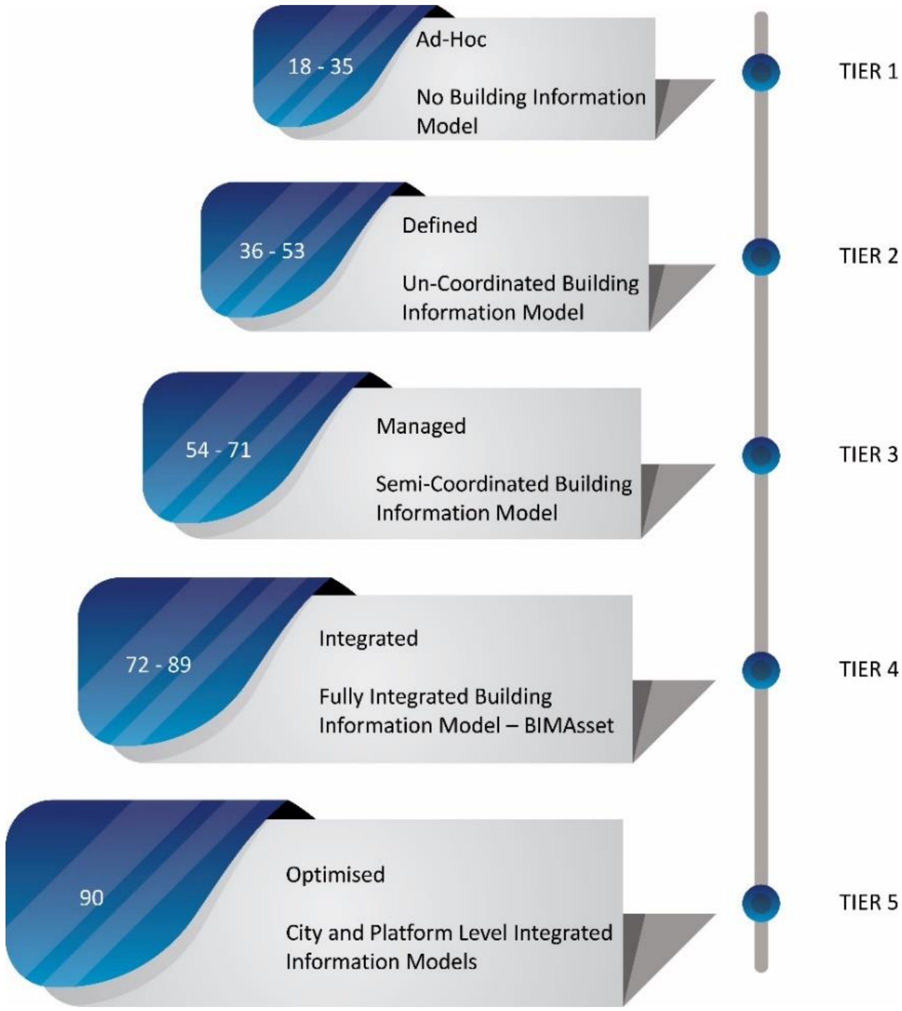


Figure 10.2: Validated BIMAsset Maturity Model (BAMM)

CHAPTER 11

SUMMARY AND CONCLUSIONS

UNIVERSITY OF LIVERPOOL

11.0 SUMMARY AND CONCLUSIONS

11.1 CHAPTER INTRODUCTION

This thesis develops a BIMAsset Value Realisation Model (BIMAsset VRM) that aims to guide asset owners in realising BIM business value in an AM system. This chapter summarises the thesis outcomes and presents the study conclusions. It covers the attainment of objectives, academic and practice-based contributions, study limitations and suggestions for future research.

11.2 THESIS SUMMARY

The main aim of the study is to research on the phenomenon of BIM business value and develop a model to help guide asset owners in realising business value of BIM implementation in an AM system throughout the lifecycle of assets. The scope of the study is limited to the client as an asset owner, asset operations in relation to AM lifecycle and BIM implementation during asset operations. However, the research outcomes may be applicable to other client types and phases of BIM and AM lifecycles.

The literature review is used to describe the rationale for this study. It is also used to identify gaps in knowledge in relation to BIM business value realisation in AM. The study identifies that in order to address the socio-technical challenge of realising BIM business value in asset operations, there is a need to address knowledge gaps in the following areas:

- The lack of knowledge and understanding amongst asset owners in the development of operational information requirements for BIM-based processes.
- The lack of understanding on techniques for integrating BIM-AM systems during asset operations.
- The lack of understanding of tools and techniques for effectively managing asset data.
- The lack of understanding of key business processes that drive BIM business value during asset operations

- The lack of understanding on approaches, tools and techniques for evaluating BIM business value during asset operations.

The study is classified into eight methodological phases as suggested by the CIFE '*horseshoe*' namely; observed problem, intuition, theoretical point of departure, research questions, research tasks and methods, results validation, claimed contributions and predicted impact (Kunz and Fischer, 2007). The study adopts a relativist and interpretivist ontological and epistemological stance, respectively. Abductive reasoning is the selected research approach for this study. The research strategies adopted are case study, archival analysis and grounded theory. Methodical choices are qualitative, exploratory and descriptive. Data collection involved semi-structured interviews and document analysis. The time horizon for the study is cross-sectional. Focus groups in the form of expert panels are used to validate the BIMAsset VRM. Model development in this study is achieved through data sourced from participants.

The BIMAsset VRM is developed abductively from the five studies carried out (Chapters 4-8). Its development and progression throughout the course of the study are achieved in eight versions, as shown in Appendix D. The main scientific contribution of the study is the BIMAsset VRM. Section 11.4.1 covers the scientific contribution in detail. Similarly, the main practical contribution of this study is the deployment of BIMAsset VRM and BIMAsset Maturity Model (BAMM) in the form of a guide in an owner-operator organisation. Section 11.4.2 covers the practical contribution in detail.

The BIMAsset VRM and BAMM are validated through expert opinion in a six-member focus group setting based on: fruitfulness, prudence, quantification, scope, progressiveness, internal consistency and external consistency (Proctor and Capaldi, 2006). The results of the focus group show that there is a majority opinion that the BIMAsset VRM satisfies the above validation criteria. Furthermore, in the data analysis, there is a majority opinion that the BAMM satisfies the above validation criteria.

The study covers a wide range of future research possibilities that are related to the theoretical and practical implementation of BIM in AM. Aspects concerning the development of operational information requirements, further weighting of BIM governance dimensions in relation to the BAMM appraisal criteria and testing of the BIMAsset VRM in use cases. This is discussed in detail in Section 11.5.

11.3 ATTAINMENT OF OBJECTIVES

This section appraises the research outcomes with the same metrics that were used to define the research problem (Fischer, 2006). The research is conducted to develop a model that will help guide asset owners to realise BIM business value in an AM system. Six objectives were designed to achieve the research aim. These are shown in Figure 11.1.

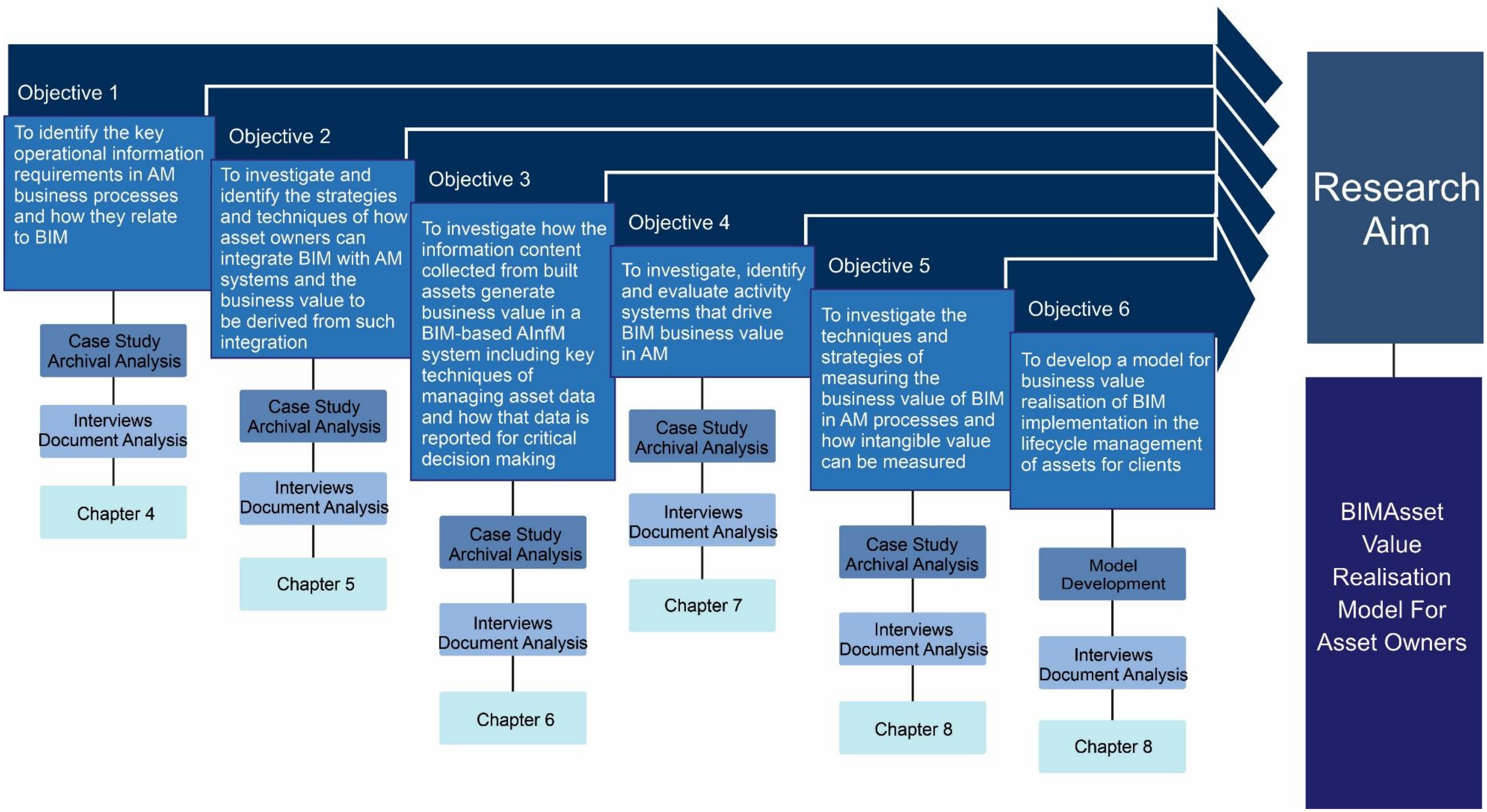


Figure 11.1: Attainment of objectives

11.3.1 OBJECTIVE 1: TO IDENTIFY THE KEY OPERATIONAL INFORMATION REQUIREMENTS IN AM BUSINESS PROCESSES AND HOW THEY RELATE TO BIM

The first objective is to identify the critical operational information requirements in AM business processes and how they relate to BIM. To achieve this research objective, the following research question is developed: **SRQ-1 –** What are the important and common information requirements for AM processes and how do these requirements relate to BIM? In answering this research question, multi-case study and archival analysis strategies are utilised. The researcher used semi-structured interviews and document analysis to collect data. From the data analysis, it has been shown that operational information requirements are strongly related to business needs and that it is not possible to develop a rigid list of requirements for asset owners. The data analysis highlights that clients utilise a strategy of focusing on selected information requirements that are critical to their business processes. Furthermore, the cross-case analysis showed that in the 172 analysed operational information requirement types, only 7 requirements were common in all cases, and 16 were common in two cases which represents 4% and 9% of the total requirement types respectively. Furthermore, the study identifies three different strategies for developing operational information requirements; '*Co-development*', '*Environment of Care*' and '*Data Ambassadors*'. The findings helped identify the BIMAsset sub-element that covers the requisition of operational information requirements for BIM-based processes. These contributions to knowledge form the attainment of the first research objective.

11.3.2 OBJECTIVE 2: TO INVESTIGATE AND IDENTIFY THE STRATEGIES AND TECHNIQUES OF HOW ASSET OWNERS CAN INTEGRATE BIM WITH AM SYSTEMS AND THE BUSINESS VALUE TO BE DERIVED FROM SUCH INTEGRATION

The purpose of the second objective is to identify techniques and strategies for integrating BIM and AM systems and how they are related to BIM business value. To achieve this research objective, the following research question is developed: **SRQ-2 –** What are the techniques and strategies of streamlining BIM-AM systems and what information should be captured from physical assets towards BIM-based integration? In answering this research question, case study and archival analysis strategies are utilised. The researcher used semi-structured interviews and document analysis to collect data. In other words, the development of OIRs. The data analysis shows that one of the reasons of the slow adoption of BIM in AM is the AEC industry perception of BIM, which is seen as a 3D-model, not as an information model nor information management tool. Furthermore, this study suggests BIM data governance procedures, BIM change management strategies, BIM stakeholder management approaches and BIM performance management techniques. BIM data governance procedures in this section relate to the development of organisational information requirements, systems architecture, asset register and asset hierarchy for BIM-based AM processes. BIM change management strategies involve the development of an organisational BIM strategy, including implementation approaches for BIM-based AM processes. BIM stakeholder management approaches pertain to stakeholder discovery, engagement and workshops during implementation and strategy development for BIM-based AM processes. BIM performance management techniques refer to the organisational processes for the development of a full business case for BIM implementation, value identification, value realisation and challenges or factors that hinder the implementation of BIM-based AM processes. One of the more significant findings to emerge from this study is that for an organisation to be successful in streamlining asset data with BIM systems, the following key issues have to be considered: (a) the development for a clear strategy prior to adoption; (b) connecting the strategy to the business goals; and (c) the discovery of organisational information needs in relation to business processes. Finally, this study offers some important insights into the business value of BIM-based integration in AM, including value realisation management processes. The findings in this study will help to guide asset owners that are seeking to implement BIM in AM to be able to realise business value from BIM-AM systems integration. The findings helped identify the BIMAsset sub-elements that cover the development of organisational information requirements, strategy, policy and systems architecture for BIM-based processes. All of these contributions to knowledge shape the achievement of the second research objective.

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11.3.3 OBJECTIVE 3: TO INVESTIGATE HOW THE INFORMATION CONTENT COLLECTED FROM BUILT ASSETS GENERATE BUSINESS VALUE IN A BIM-BASED AInfM SYSTEM INCLUDING KEY TECHNIQUES OF MANAGING ASSET DATA AND HOW THAT DATA IS REPORTED FOR CRITICAL DECISION-MAKING

The third objective aims to investigate how the information content collected from built assets generate business value in a BIM-based AInfM system. To achieve this research objective, the following research question is developed: SRQ-3 – How does the information content captured from physical assets generate business value in AM and which aspects relate to BIM? In answering this research question, case study and archival analysis strategies are utilised. The researcher used semi-structured interviews and document analysis to collect data. A key finding of this study is the identification of important techniques of managing asset data and how that data is reported for critical decision-making. This involves key BIM-based data collection, formats, sources, transfer, management, analysis and reporting strategies. Also, it clarifies certain aspects of data requirements that will assist asset managers in filtering valuable asset information from the large pool of information sets for strategic reporting and timely decision-making across their portfolio. The findings in this study suggest that there is real value to be derived by the asset owner from the effective management of asset information. Furthermore, the study shows there is the potential to do different types of analysis with building automation systems, AInfM and BIM systems in order to optimise assets and realise the value the end of the process. The study identifies six typologies of BIM business value in AM, which are; management, commerce, efficiency, industry, user and technology value. Finally, the study identifies the barriers to BIM implementation in an AInfM system. These factors play a role in the slow adoption of BIM and as barriers in the realisation of BIM business value during asset operations. The findings helped identify the BIMAsset elements of input and output for BIM-based processes. This study makes several noteworthy contributions to knowledge, and this confirms the achievement of the fourth objective.

11.3.4 OBJECTIVE 4: TO INVESTIGATE, IDENTIFY AND EVALUATE ACTIVITY SYSTEMS THAT DRIVE BIM BUSINESS VALUE IN AM

The main goal of the fourth objective is to bring to light the important business processes that drive the business value of BIM utilisation in AM. To achieve this research objective, the following research question is developed: **SRQ-4 –** What are the vital AM business processes that drive BIM business value and how do they relate to business process maturity? In answering this research question, multi-case study and archival analysis strategies are utilised. The researcher used semi-structured interviews and document analysis to collect data. The main contribution of this study is the identification of six key activity systems that drive BIM business value for an asset owner, and they are; BIM strategy, lifecycle management, maintenance management, work-order management, contracts management and value realisation management. The six main activity systems cover a wide spectrum of AM business processes during asset operations. Another contribution of this study is the emphasis on the need for a reasonable state of maturity of the six activity systems and the establishment of continuous improvement across the board in order to realise BIM business value in AM. The third major contribution of this Objective is the demonstration of a novel approach for evaluating organisational maturity of asset owners in executing the identified six activity systems from the perspectives of BIM governance dimensions of people, process and technology. The assessment technique demonstrated in this study is aimed at assisting asset owners in evaluating organisational business processes in relation to BIM business value realisation. Finally, the study identifies barriers of BIM business value realisation management in asset operations. The elimination of these factors will play a role in the realisation of BIM business value. The findings helped identify the BIMAsset sub-elements that cover people, process and technology as influencers of the BIM-based processes. These novel contributions to knowledge shape the achievement of the fifth research objective.

11.3.5 OBJECTIVE 5: TO INVESTIGATE THE TECHNIQUES AND STRATEGIES OF MEASURING THE BUSINESS VALUE OF BIM IN AM PROCESSES AND HOW INTANGIBLE VALUE CAN BE MEASURED

The fifth objective seeks to demonstrate how owner-operator organisations can link intangible to tangible value for easy measurement. To achieve this research objective, the following research question is developed: **SRQ-5 –** What are the techniques and strategies for measuring the business value of BIM in AM processes and how can intangible value be linked to tangible value? In answering this research question, an archival analysis strategy to study secondary data is utilised. This data is used to inductively develop a framework that will guide asset owners in measuring intangible value. Measuring intangibles is very difficult because it is not always possible to quantify those values in absolute terms without any degree of subjectivity. Furthermore, in order to measure or quantify the intangible business value of BIM, intangible value will have to be linked with tangible outcomes. The main contribution of this study is the development of a novel framework that can be used by asset owners to link intangible to tangible value through a concept map in four stages. That starts from the BIM property, to identification of intangible value, linking to semi-tangible value and tangible value. The BIM-based process may be evaluated using value measurement techniques proposed in the concept map. Business value linkage is a technique which can assist asset managers in identifying value and understanding the process through which value is created. Finally, the study highlights the need for asset owners to establish benchmarks so as to improve linkage and measurement metrics over time. The findings helped identify the BIMAsset sub-elements that cover tangible, value, intangible value, real-time data update, data security and BIMAsset CDE including value realisation at user, system, business, ecosystem levels for BIM-based processes These contributions to knowledge form the attainment of the sixth research objective.

11.3.6 OBJECTIVE 6: TO DEVELOP A MODEL FOR BUSINESS VALUE REALISATION OF BIM IMPLEMENTATION IN THE LIFECYCLE MANAGEMENT OF ASSETS FOR CLIENTS

The sixth research objective aims to develop a model that will guide asset managers to derive BIM business value in an AM system during asset operations. To achieve this research objective, the following research question is developed: **PRQ –** How can the BIMAsset VRM support asset managers in deriving BIM business value? In answering this research question, the researcher utilised the outcomes of Objectives 1-5 to develop inductively a novel framework that will help guide asset owners to derive BIM business value, which is the main contribution of this study. This study develops the BIMAsset VRM in eight versions as shown in Appendix D. The proposed model is conceptual in nature and it provides the underlying foundation for developing a strategy for asset owners to consider how BIM can create value which will lead to sustainable competitive business advantage. This study demonstrates the capabilities of the BIMAsset VRM in the: (a) definition of key requirements for AM processes; (b) identification of organisation set-up for effective AInfM; (c) establishment of metrics for tracking, managing and measuring BIM business value; and (d) maturity appraisal for asset owners in relation to BIM business value realisation. The framework developed in this study extends the current knowledge base and confirms the attainment of the seventh objective.

11.4 CONTRIBUTION TO KNOWLEDGE

The theoretical significance of the research questions is to enhance the understanding of: what information should be requested; how the information should be captured and managed; what are the valuable information attributes; how outcomes can be observed; and how value can be tracked in an AM system during asset operations. The practical significance of the research questions is to develop a framework that will guide asset owners in tracking tangible and intangible value for measurement in an AM system. The presented framework in this study can be utilised to understand the phenomena of BIM business value and as an outcome of effective AInfM though BIM-based processes. The theoretical and practical contributions that have emanated from this study are as follows:

11.4.1 ACADEMIC BASED CONTRIBUTION

The main scientific contribution of the study is the BIMAsset VRM. The study has made significant contributions on what information should be requested by the asset owner for BIM-based processes. In Chapter 4 some of these important datasets are classified under the headings of general classification, standard description, general description, location description, installation description, product description, technical description physical description and model reference. Some of the datasets such as (but not limited to): data type, object, reference to model, attribute set, location, service area code, installation date, LOD, position, thickness, volume and weight. The study makes another scientific contribution by highlighting how asset information should be captured and managed. In Chapter 5 it demonstrates the effective management of asset data for BIM-based processes through and AInfM. The study also highlights three levels of management to achieve that: strategic, tactical and operational. Additionally, the study contributes to the identification of valuable attributes for data. These are indices that highlight the achievement of management and operational KPIs such as (but not limited to): energy consumption, operability, indoor conditions, service requests, maintenance plan. Another fundamental contribution is the presentation of a model that would enable asset managers to observe outcomes and track BIM business value. In Chapter 8 the BIMAsset VRM flowchart seeks to assist asset managers to observe management and operational maintenance KPIs, evaluate the outcomes and use a four-step value realisation framework for measuring tangible and intangible value. This study makes other noteworthy scientific contributions to knowledge, they are:

- The study contributes to knowledge by deducing that operational information requirements are strongly related to business needs and that it is not possible to develop a rigid list of requirements for asset owners. This shows that in the 172 analysed operational information requirements, only 7 requirements were common in all cases and 16 were common in two cases, which represent 4% and 9% of the total requirement types, respectively.
- The research addresses a significant gap in the development of techniques and strategies for asset owners to streamline BIM with AM systems and derive business value from such

integration. The study extends the current knowledge base on techniques for integrating BIM and AM systems, including the implementation process, challenges, and the business value attained.

- Another scientific contribution is in identifying key strategic (management) and functional (operational) business activities that facilitate BIM business value realisation in an AM system and the subsequent development of a BIM business value generation theory, using a grounded theory approach.
- The study provides significant contributions to the existing knowledge base of BIM business value by identifying four key BIM business value domains (user, system, business and ecosystem) and six typologies of BIM business value (management, commerce, efficiency, industry, user and technology). In addition, the study contributes to knowledge by documenting effective strategies for BIM-based AInfM.
- The study contributes to existing knowledge of BIM business value realisation by identifying six activity systems (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management) that drive BIM business value in AM.
- Another scientific contribution is the development of a novel BAMM assessment matrix and criteria to appraise the six activity systems based on three dimensions of BIM governance (people, process and technology) in relation to BIM business value realisation management capability.
- The findings in this study enhance the knowledge base of BIM business value by presenting a four-step value realisation model for measuring tangible and intangible BIM business value. Furthermore, the study contributes to the current literature by developing a novel framework for measuring intangible value through BIM business value linkage.
- A significant scientific contribution of this study is the development of the BIMAsset VRM that contributes to the current literature of BIM business value in asset operations through six elements (influencers, input, output, drivers, core and value realisation dimension) of the model.

11.4.2 PRACTICE BASED CONTRIBUTION

The study develops a BIMAsset VRM to help guide asset owners in deriving BIM business value in an AM system in asset operations. This model is expected to have practical implications in the AEC industry in relation to value realisation management of BIM-based processes in AM. The target user of the model is the asset manager. The BIMAsset VRM through the six elements goes through the following processes of implementation: initiating input, performing tasks (BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management), generating outputs (management or operational maintenance KPIs), observing outcomes (management, commerce, efficiency, industry, user and technology value), measuring value (tangible or intangible) and realising value (user, system, business or ecosystem levels). This study makes other noteworthy practical implications; they are:

- The study presents draft templates of operational information requirements as guidance to asset owners on how clients that utilise BIM in asset operations are articulating their information requirements. These templates can improve the knowledge of asset owners and guide them in articulating their information requirements.
- The findings from this study demonstrate practical implementation strategies of BIM in AM and highlights the significance of establishing a business process for identifying and articulating organisational information requirements within an owner-operator organisation. The step-by-step methodology is presented for easy implementation by asset owners.
- This study makes noteworthy practical contributions by presenting step-by-step processes for efficient AInfM in an owner-operator organisation. The study demonstrates how data creation, storage, management and reporting strategies as a guide to asset managers for implementation.
- A practical implication of the BAMM assessment matrix and criteria is the enhanced understanding of asset owners of their organisations and how they can practically appraise the maturity of owner-operator organisations in relation to BIM business value realisation.

- The main practical contribution of this study is in presenting an implementation guide for the BIMAsset VRM. The study discusses in great detail how an asset manager can plan, manage and implement the six dimensions of BIMAsset VRM in asset operations. Also, it presents a guide for tracking and measuring tangible and intangible BIM business value.

11.5 FUTURE RESEARCH

The study opens up certain interesting aspects of BIM implementation and BIM business value realisation during asset operations. Although the study has succeeded in identifying the phenomena, the study could not cover some aspects because it was not within the scope of the research questions. Future studies on this topic are therefore recommended:

1. A broader scope of data collection may be considered to involve other types of clients. This study only covered five perspectives; retail, education, health, government and consultants. A more diverse study may identify other factors relevant to BIM business value in an AM system during asset operations.
2. An important issue for future research is to identify the complex relationship between business needs and operational information requirements. This may be needed to critically identify the vital information requirement needs for asset operations and the establishment of right contexts for such requisition.
3. Other research questions could be asked that would lead to the development of meta-requirements for operational information requirement templates. This may be needed to provide an insight into how asset owners can be guided in developing their operational information requirements through a meta-requirement framework.
4. A further study may be conducted to determine the weighting of the dimensions of BIM governance in relation to the BAMM assessment matrix and criteria. The governance dimensions are; people, process and technology. This will enable a wider identification of the impact factor that these dimensions have on organisational maturity and BIM business value.
5. However, more research on this topic could be undertaken to identify the critical processes within the identified six activity systems (BIM strategy, contract management, lifecycle

management, maintenance management, work-order management and value realisation management) in an AM system and in what order they derive value so that these phenomena are understood.

6. In future investigations, it might be possible to test the BIMAsset VRM in practical use cases within the AM system of an owner-operator organisation.

11.6 LIMITATIONS

This section outlines the limitations of this study. BIM in AM is a field where little research has been conducted. The researcher encountered limitations in gaining access to respondents for data collection. The phenomenon of BIM-based AM is new, and asset owners in the AEC industry are still trying to understand how to manage BIM implementation. As a result, the study is faced with limited practical implementation of BIM in AM, therefore, limiting the sample size for data collection. Hence, the limitation in gaining access to data.

Secondly, another limitation encountered by the researcher is the nature and sensitivity of AM business processes in relation to the asset owner. Most of the organisations that were contacted were not interested in participating because they felt that aspects of AM within the research scope is very sensitive to their businesses and were unwilling to participate and release financial data. In some cases, there were requests for non-disclosure agreements (NDAs) by the industry contacts in order to release research data. These proposals were abandoned because of the complicated process of signing NDAs with the University and the time constraints of the study. Although the notion of value in this research is economic, this limitation has led to the lack of presentation of quantitative economic business value in this study. As a result, the research provided an overview of BIM business value from the perspective of tangible and intangible value, including metrics for evaluation.

Thirdly, the study only covered five perspectives of BIM implementation in AM, which are; retail, education, health, government and consultants. This was as a result of the time constraints of the study and limited implementation of BIM in AM business processes as mentioned above.

Furthermore, there is always a limit on the number of cases or types of asset owners that can be sampled for study considering the large variation of typologies of asset owners in Appendix E.

Finally, this study is based on the client as an asset owner and not the facility manager nor end-user. Also, the scope is limited to the operations phase of BIM implementation and not the other phases of BIM lifecycle. Furthermore, the current study focuses on asset operations and not the other phases of AM lifecycle. This is expressed in Section 1.2 of this thesis.

11.7 CONCLUSIONS

The realisation of BIM business value is dependent on the adoption of a suitable socio-technical approach by asset owners as proposed by this study. Therefore, it is imperative to develop understanding within the subject areas that affect value realisation as highlighted in the knowledge gaps with a view of providing a methodical approach to BIM business value realisation in AM. Therefore, the study addresses the first research gap by improving the understanding of the development owner information requirements. Subsequently, the research addresses the second research gap by investigating how to effectively integrate BIM and AM systems during asset operations in order to derive BIM business value. This study follows through on implementation strategies that cover the development of information requirements, data governance, systems architecture, change management and value realisation management. The research addresses the third research gap by investigating how the information content captured from built assets generate BIM business value. It provides valuable demonstrations of how information created from the BIM-based AM systems could generate business value for the asset owner. Also, this aspect identifies typologies of BIM business value in relation to effective AInfM. The study addresses the fourth research gap extending the investigation to identify the key activity systems that drive BIM business value through a cross-case analysis. Also, the study develops and utilises a maturity matrix to appraise owner-operator organisations in relation to the activity systems and BIM governance dimensions which are critical success factors to BIM business value realisation. The research addresses the fifth research gap by exploring value realisation techniques and developing a four-step methodology for evaluating tangible and intangible value.

Furthermore, the outcomes are synthesised in order to address the knowledge gap identified in the overall thesis problem statement. This study develops a framework for addressing challenges of BIM business value realisation in AM covering: (a) information requirement strategies; (b) BIM-AM systems integration techniques; (c) information content management tools and techniques; (d) activity systems that drive BIM business value; and (e) techniques for tracking and measuring tangible and intangible value in BIM-based processes. These sequential studies ensured that the PhD thesis extends the current knowledge base and provides a cradle-to-grave approach to addressing the phenomenon of BIM business value realisation in an AM system during asset operations.

The findings in this PhD thesis can lead to the following conclusions. First, the study identifies that operational information requirements are strongly related to business needs and that there cannot be a rigid requirement list for all clients. Second, in order to successfully integrate BIM-AM systems, the owner-operator should consider the following: (a) the development for a clear strategy prior to adoption; (b) connecting the strategy to the business goals; (c) the discovery of organisational information needs for the development of information requirement templates. Third, there is real value to be derived by the asset owner from the effective management of asset information, and there are six typologies of BIM business value that can be derived in AM, they are; management, commerce, efficiency, industry, user and technology value. Fourth, the study identifies BIM strategy, contract management, lifecycle management, maintenance management, work-order management and value realisation management as activity systems that drive BIM business value in AM. Fifth, the study has revealed that the capability of asset owners to derive business value of BIM in AM has implementation and maturity implications. Sixth, the findings suggest that intangible value can be tracked and measured through the activity of business value linkage using concept maps. Seventh, the entire process of BIM business value realisation management is about driving change, measuring outcomes and continuous improvement of activity systems that drive value so as to validate predicted desirable outcomes, discover the unpredicted desirable outcome, and eliminate both predicted and unpredicted undesirable outcomes within the BIM-based AM system.

The use of BIM to enhance AM processes may increase as asset owners see the rationale of making BIM-based investments. Hence, BIM will continue to disrupt business processes in the AEC industry. Therefore, it is necessary for asset owners to be able to manage such disruption. This research results in a novel framework that provides the opportunity for asset owners to track, measure and manage BIM business value in the lifecycle of assets. Once clients or asset owners are able to realise the real business value of BIM in AM, its adoption will inevitably increase.

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13.0 APPENDIX A: ETHICAL APPROVAL

School of the Arts Committee on Research Ethics

5 May 2017

Dear Prof Kiviniemi,

I am pleased to inform you that your application for research ethics approval has been approved. Details and conditions of the approval can be found below:

Reference:	1776
Project Title:	ENHANCING VALUE OF PHYSICAL ASSETS THROUGH THE DEVELOPMENT OF A BUILDING INFORMATION MODELLING ASSET (BIMASSET) VALUE REALISATION MODEL
Principal Investigator/Supervisor:	Prof Arto Kiviniemi
Co-Investigator(s):	Mr Mustapha Munir, Dr Steve Jones
Lead Student Investigator:	-
Department:	Architecture
Reviewers:	Dr Torsten Schmiedeknecht, Dr Iain Jackson
Approval Date:	05/05/2017
Approval Expiry Date:	Five years from the approval date listed above

The application was **APPROVED** subject to the following conditions:

Conditions

- All serious adverse events must be reported via the Research Integrity and Ethics Team (ethics@liverpool.ac.uk) within 24 hours of their occurrence.
- If you wish to extend the duration of the study beyond the research ethics approval expiry date listed above, a new application should be submitted.
- If you wish to make an amendment to the research, please create and submit an amendment form using the research ethics system.
- If the named Principal Investigator or Supervisor leaves the employment of the University during the course of this approval, the approval will lapse. Therefore it will be necessary to create and submit an amendment form using the research ethics system.
- It is the responsibility of the Principal Investigator/Supervisor to inform all the investigators of the terms of the approval.

Kind regards,

School of the Arts Committee on Research Ethics
sotares@liverpool.ac.uk

14.0 APPENDIX B: INTERVIEW QUESTIONS

APPENDIX B1: STUDY 1

UNIVERSITY OF LIVERPOOL

STUDY1: BUSINESS VALUE OF OPERATIONAL INFORMATION REQUIREMENTS

INTERVIEW QUESTIONS

S/NO.	QUESTION	PURPOSE OF QUESTION
1	What is your role in the organisation?	To identify respondents role in the organisation.
2	What are the daily tasks that you perform in the organisation?	To identify the daily tasks respondents execute in the organisation.
3	Does the organisation have a standard template for documenting users' informational needs? If yes, what are they or what has been documented so far?	To investigate the organisational processes and how documentation is done for information requirements. To review the current template for information requirements (if any)
4	Describe your current system of documenting Employer's Information Requirements (EIR), Asset Information Requirements (AIR) and Organisational Information Requirements (OIR)?	To investigate the organisational processes and how documentation for these deliverables are executed. The respondents will explain how the processes are executed.
5	Does your organisation follow a formal process to prepare the above documents? If yes, is that process documented? Please list the major steps in the process. Is there a standard format (layout) used for documenting OIR, AIR and EIR?	To determine the extent to which the organisation recognises the importance of this process. To Investigate how mature the process is and how widely understandable is it in the organisation. To understand the scope of the procedure in place, looking for linkages to other processes. To identify organisational standards of information requirements.
6	Who is responsible for documenting the above requirements in your organisation? List the key stakeholders responsible for putting together the handing over documents for asset management information to your organisation at handover stage. Which Department is responsible for such activity?	To identify the party responsible in the organisation for this task. To identify if the process requires inter-disciplinary or inter-organisational processes. The respondents will describe the party/department responsible for executing such tasks in the organisation.
7	Which department in your organisation is responsible for receiving handover information for effective Asset Management?	To identify the department responsible for receiving handover information for effective Asset Management.
8	What type of software are you using for Asset Management?	To identify which software the organisation utilises for Asset Management activities.
9	What type of software are you using for Building Information Modelling?	To identify which software the organisation utilises for Building Information Modelling activities.
10	Have the roles for documentation for the delivery of asset management information been clearly stated in the contractual documents?	Identify the party responsible contractually for delivery of asset management information. The respondents will elaborate on who is contractually responsible for documentation at handover?

	If yes, who is responsible? If no, from which party do you source for such information?	
11	What are the challenges that you have experiences in documenting your Employer Information Requirements for BIM processes?	To identify if these challenges are related to the documentation process.

APPENDIX B2: STUDY 2

STUDY 2: BUSINESS VALUE OF INTEGRATED BIM-BASED ASSET MANAGEMENT

INTERVIEW QUESTIONS

S/NO.	QUESTION	PURPOSE OF QUESTION
1	Does your organisation have a standard process for developing the asset register? If yes, how is that process documented? Please list the major steps in the process.	To investigate if the organisation has a standard process for developing an asset register. To identify the techniques/tool used to achieve such task. Understand the scope of the processes in place, looking for linkages to other processes.
2	Does your organisation have an up-to-date asset register?	To investigate how the organisation operates an up-to-date asset register.
3	What software does your organisation deploy in Asset Management?	To identify which software the organisation utilises for Asset Management activities.
4	What software does your organisation deploy in Building Information Modelling?	To identify which software the organisation utilises for Building Information Modelling activities.
5	Is there smooth interoperability between the Asset Management and Building Information Modelling software? If no, what are the challenges?	To investigate if there is seamless communication between the two software. To identify the challenges experienced by respondents in using such systems.
6	What are your organisational objectives for streamlining assets for BIM-based integration?	Investigation in the organisation's expectation of Building Information Modelling implementation in Asset Management? The respondents will explain the organisational purpose of implementing Building Information Modelling implementation in Asset Management?
7	Who is responsible for streamlining assets for BIM-based integration in your organisation? Which Department is responsible for such activity?	Identify the party responsible in the organisation for such activity. The respondents will describe the department responsible for executing such tasks in the organisation.
8	Briefly explain how your organisation initiated the adoption of Building Information Modelling in Asset Management?	To test for existence of a formal process for Building Information Modelling adoption. The respondents will elaborate how the organisation arrived at the decision of adopting Building Information Modelling as a solution.
9	What are the processes your organisation followed in developing a solution for Building Information Modelling based integration with Asset Management?	To investigate the organisational processes and how the documentation was done for Building Information Modelling based integration. The respondents will explain how the processes are executed.

APPENDIX B3: STUDY 3

UNIVERSITY OF LIVERPOOL

STUDY3 : BIM BUSINESS VALUE OF AN ASSET INFORMATION MANAGEMENT SYSTEM

INTERVIEW QUESTIONS

S/NO.	QUESTION	PURPOSE OF QUESTION
1	What is your role in the organisation?	To identify respondents role in the organisation.
2	What are the regular tasks that you perform in the organisation?	To identify the daily tasks respondents execute in the organisation.
3	How long have you been using BIM?	To identify the years of experience of using BIM by the respondent.
4	How long have your organisation been using BIM?	To identify the years of experience of using BIM by the respondent.
5	What are your organisational objectives for Asset Information Management (AIM)?	To investigate the organisation's expectation of AIM. The respondents will explain the organisation's purpose on utilising AIM Systems.
6	What are your organisational objectives for implementing BIM?	To investigate the organisation's expectation of implementing BIM The respondents will explain the organisation's purpose on utilising AIM Systems.
7	Briefly describe the processes of collecting information at the operational level?	To test for existence of a formal process for collecting asset information within the organisation. The respondents will describe the processes involved within this task.
8	Do you have a template for capturing operational asset requirements for the above process? If yes, what are the requirements?	To investigate the organisational standards for requesting operational information requirements for assets.
9	What is the content of information collected at the operational level?	To investigate the information content collected for the AIM system.
10	Briefly describe the process of transferring data to the database after collection?	To test for existence of a formal process for sharing asset information within the organisation. The respondents will describe the processes involved within this task.
11	Briefly describe the process of data handling and storing?	To test for existence of a formal process for managing and storing asset information within the organisation. The respondents will describe the processes involved within this task.
12	Briefly describe the process of reporting at the operational level?	To test for existence of a formal process for reporting asset information at the operational level within the organisation. The respondents will describe the processes involved within this task.
13	Briefly describe the process of reporting at the tactical level?	To test for existence of a formal process for reporting asset information at the tactical level within the organisation.

		The respondents will describe the processes involved within this task.
14	Briefly describe the process of reporting at the strategic level?	To test for existence of a formal process for reporting asset information to top management within the organisation. The respondents will describe the processes involved within this task.
15	Do you have challenges in the implementation of the AIM systems? If yes, what are the main challenges?	To investigate the challenges faced by respondents in the AIM process.
16	Is your asset information currently linked to 3D geometric data?	To investigate the maturity level of the organisational AIM System.
17	What is your organisation's current Building Information Modelling capability?	To investigate the organisational maturity level of BIM.
18	In what format do you collect and distribute data?	To identify the format of file exchange used by the organisation.
19	What are the main organisational goals for strategic AIM reporting?	To investigate the organisational strategy for asset data reporting using AIM systems.
20	To what extent does the systems and techniques of strategic reporting reduce reactive maintenance?	To investigate the extent at which strategic reporting would reduce reactive maintenance.
21	What is the typical reporting cycle of the AIM system from the operations level to senior management level?	To identify how responsive the system is to changes in asset information input.

MANAGER SPECIFIC QUESTIONS		
1	How does the Manager give visibility to ownership of asset data and at what levels?	To identify how the system improves asset information delivery.
2	What are the typical processes when using manager in planning and subsequent maintenance actions?	To identify the processes involved in maintenance activities.
3	How are these processes related to BIM?	To identify the if any of the processes are related to BIM.
4	How does Manager store all asset data?	To identify the processes involved in data management using Granlund Manager.
5	How can the asset data be shared through the supply chain?	To identify the processes involved in data sharing across the supply chain.
6	Describe the process of logging maintenance requests and maintaining visibility throughout the process.	To identify the processes involved in maintenance activities.

METRIX SPECIFIC QUESTIONS		
1	How does the use of Metrix improve the operation and maintenance of buildings?	To identify how the system improves asset maintenance.
2	Does Metrix report real-time asset information of the building?	To identify if the system reports real-time asset data.
3	How is that data collected for built assets?	To identify the process of collecting data from assets.
4	What is the content of information required for the system for system input?	To identify the type of information required by the system for strategic reporting.

	Is there a template for such data requirement?	To identify if there is a standard format for data requisition.
5	What are the performance indicators used by Metrix to monitor Assets?	To identify the standard performance indicators the system.
6	How does Metrix report those indicators?	To identify the processes and how responsive the system is in real-time information delivery.
7	How does Metrix anticipate or predict asset failure in real-time?	To identify how the system assists asset owners in preventive maintenance.
8	What sort/types of analysis can be conducted for assets using Metrix?	To identify the types of forecast/evaluation that can be conducted by the Metrix system.

DEVELOPER SPECIFIC QUESTIONS		
1	How does any of your digital AIM systems work with BIM systems?	To identify if BIM is currently utilised for AIM.
2	Does Granlund Manager automatically take information from building Models? If yes, briefly describe the process of asset data collection at the operational level?	To identify the processes involved in data collection for BIM based processes.
3	Do you have a standard template for data requirement for BIM processes? If yes, what are the requirements?	To identify the data required for BIM-based processes.
4	How does the Granlund Manager report asset information at the strategic level whilst using BIM-based processes?	To identify the processes involved in strategic reporting using BIM-based processes.

APPENDIX B4: STUDY 4

STUDY 4: BUSINESS VALUE OF BIM-BASED ACTIVITY SYSTEMS IN ASSET MANAGEMENT

INTERVIEW QUESTIONS

S/NO.	QUESTION	PURPOSE OF QUESTION
1	What is your role in the organisation?	To identify respondents role in the organisation.
2	What are the daily tasks that you perform in the organisation?	To identify the daily tasks respondents execute in the organisation.
3	Has the utilisation of BIM/DIT improved the management/ operation of your assets? If yes, how have they improved your business processes? How well would you say the utilisation of BIM support your business processes in optimising your assets?	To investigate how digital technologies have impacted the operation of assets in the organisation. To investigate how digital technologies support business processes. To investigate the extent at which digital technologies support business processes.
4	How has the utilisation of BIM/DIT impacted your strategic, planned and unplanned asset interventions? Have you been able to plan your interventions better?	To investigate the how digital technologies have influenced the organisational culture towards the maintenance of assets. To investigate how digital technologies support asset intervention planning.
5	What percentage of your asset interventions do you use BIM/DIT to support your business processes?	To identify the level of deployment if IT in delivering information for facility/asset management processes.
6	Can you explain to me the basic processes of how you use BIM/DIT in for example work order management?	To identify the level of deployment if IT in work order management processes.
7	How does the use of BIM/DIT aid your organisation in contracts management?	To identify the level of deployment if IT in contract management processes.
8	How does the use of BIM/DIT aid your organisation in long-term planning?	To identify the level of deployment if IT in lifecycle planning processes.
9	Is your organisation able to measure the benefits of BIM-related project performance against established business cases? If yes, how?	Identify if the organisation has a pre-existing method of measuring BIM performance.
10	Does your organisation follow a formal process to set Key Performance Indicators for value realisation of BIM/DIT in facility operation? If no, how do you identify the success factors in projects? If yes, is that process documented? Please list the major steps in the process.	Determine the extent to which the organisation aims to derive value for BIM implementation in projects. Identify how the organisation measures success of BIM projects. How mature is the process and is it widely known? Understand the scope of the process in place, looking for linkages to other processes.

	Is there a standard format (layout) used for documenting KPI's?	Identifying organisational standards of value realisation.
11	How do you know/identify the user information requirement for BIM-based workflows in asset maintenance that will be imputed in the system?	To test for existence of a formal process for documenting user information requirements within the system. The respondents will describe the processes involved within this task.
12	In what format do you collect and distribute data?	To identify the format of file exchange used by the system (BIM-based asset maintenance workflows).
13	Is there smooth interoperability between all software within the system (i.e. your BIM-based Facility Management workflows)? If no, what are the challenges?	To investigate if there is seamless communication between all software within the system. To identify the challenges experienced by respondents in using such systems.
14	Can you give factual examples of benefits that you have derived from the use of BIM/DIT in the operation of assets?	To identify if there are any factual cases of business value.
15	What are the challenges that you encounter in value realisation of BIM/DIT in the operation of assets?	To identify the challenges of value realisation of BIM in Facility/Asset Management.
16	What are the reasons for such challenges?	To identify the root cause for the challenges stated in value realisation of BIM in Facility/Asset Management.
17	How do you think those challenges of value realisation of BIM/DIT implementation in Facility/Asset Management can be overcome?	To identify possible solutions of value realisation of BIM in Facility/Asset Management.

15.0 APPENDIX C: PARTICIPANT INFORMATION SHEET AND CONSENT FORM

APPENDIX C1: PARTICIPANT INFORMATION SHEET

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

ENHANCING VALUE OF BUILDING ASSETS FOR CLIENTS THROUGH THE DEVELOPMENT OF A BUILDING INFORMATION MODELLING ASSET (BIMASSET) VALUE REALISATION MODEL

PARTICIPANT INFORMATION SHEET

1. **Title of Study**

   ENHANCING VALUE OF BUILDING ASSETS FOR CLIENTS THROUGH THE DEVELOPMENT OF A BUILDING INFORMATION MODELLING ASSET (BIMASSET) VALUE REALISATION MODEL.

2. **Version Number and Date**

   Version 1.1 – 13/04/2017

3. **Invitation Paragraph**

   Dear Participant,

   You are being invited to participate in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to ask us if you would like more information or if there is anything that you do not understand. Please also feel free to discuss this with your friends and work colleagues, if you wish. We would like to stress that you do not have to accept this invitation and should only agree to take part if you want to.

   Thank you for your time.

   Best Regards,
   Mustapha Munir

4. **What is the purpose of the study?**

   The research aims to investigate BIM benefits for clients and how it generates value for building assets. Specifically, this study is to investigate and provide a model for clients to realise business value of BIM implementation in an asset management system in the lifecycle of assets.

Version 1.1
13, April 2017

description of the study (so that it can be identified), the researcher involved, and the details of the complaint you wish to make

12. Will my participation be kept confidential?

No all responses will be kept confidential. Participants may be identifiable from the research outcome. Consent will be sought from the all participants for identifiable data.

Data will be audio recorded and subsequently transcribed. All data will be stored on the researcher's University's protected drive, where only the researcher has access. The data will be stored for the period of the study after which the data will be disposed.

13. What will happen to the results of the study?

The results will be published in journals, conferences and the PhD dissertation of the researcher. Participants will not be identifiable from the results unless they have consented to being so.

14. What will happen if I want to stop taking part?

Participants can withdraw at any time, without explanation. Results up to the period of withdrawal may be used, only if participants agree for that to be done.

15. Who can I contact if I have further questions?

The participant should contact the following for any questions:
Name: Mustapha Munir
Work Address: School of Architecture, L69 3BX
Work Telephone: 07706570630
Work Email: mmunir@liverpool.ac.uk

description of the study (so that it can be identified), the researcher involved, and the details of the complaint you wish to make

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Name: Mustapha Munir
Work Address: School of Architecture, L69 3BX
Work Telephone: 07706570630
Work Email: mmunir@liverpool.ac.uk

APPENDIX C1: PARTICIPANT CONSENT FORM

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research	Enhancing Value of Building Assets for Clients Through the Development of a Building Information Modelling Asset (BIMASSET) Value Realisation Model
Project:	PhD Dissertation
Researcher(s):	Mustapha Munir

Please initial box

1. I confirm that I have read and have understood the information sheet dated 13/04/2017 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐
3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ☐
4. I understand and agree that my participation will be audio recorded and I am aware of and consent to your use of these recordings for the purpose of this research. ☐
5. I understand that I will be identified in this interview and any subsequent publication or use. I addition I would require to review the data related to this interview about me or my organisation before it is published. ☐
6. The information you have submitted will be used in the PhD dissertation and may be used in journal or conference articles. Please indicate whether you would like to receive a copy. ☐
7. I agree to take part in the above study. ☐

Participant Name	Date	Signature
Mustapha Munir/Researcher	Date	Signature

Student Researcher:
Name: Mustapha Munir
Work Address: School of Architecture, L69 3BX
Work Telephone: 07706570630
Work Email: mmunir@liverpool.ac.uk

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Version 1.1
13 April 2017

16.0 APPENDIX D: BIMASSET DEVELOPMENT

APPENDIX C1: VERSION 1

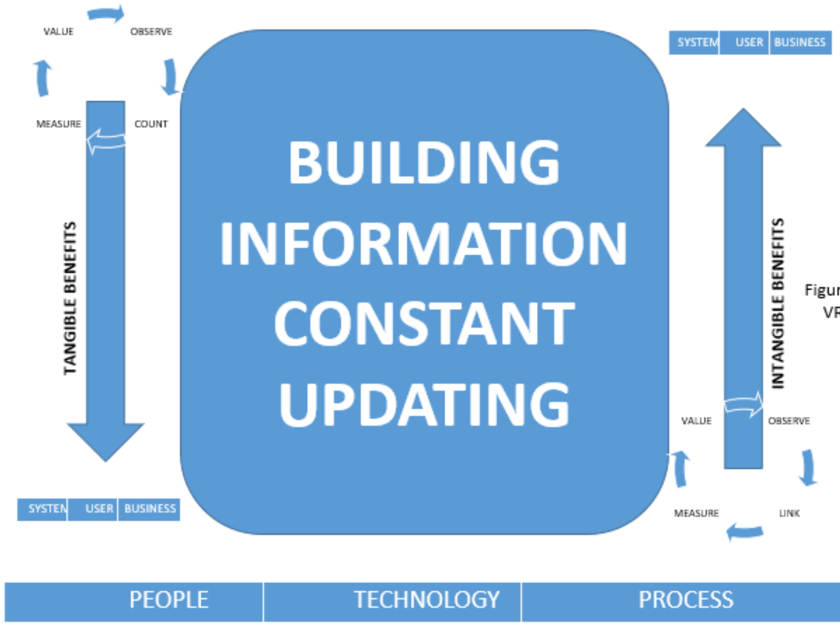

Figure 1: BIM ASSET VR SHUTTLE v1

APPENDIX C2: VERSION 2

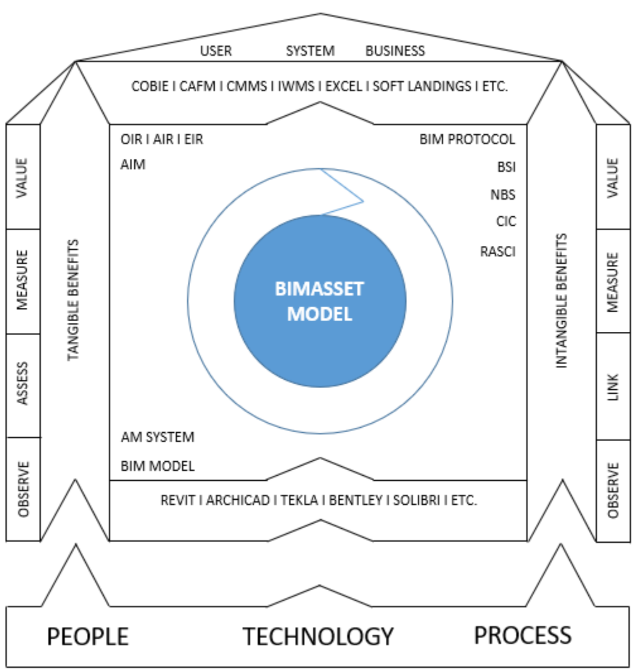

Figure 1: BIM ASSET VR SHUTTLE v2

APPENDIX C3: VERSION 3

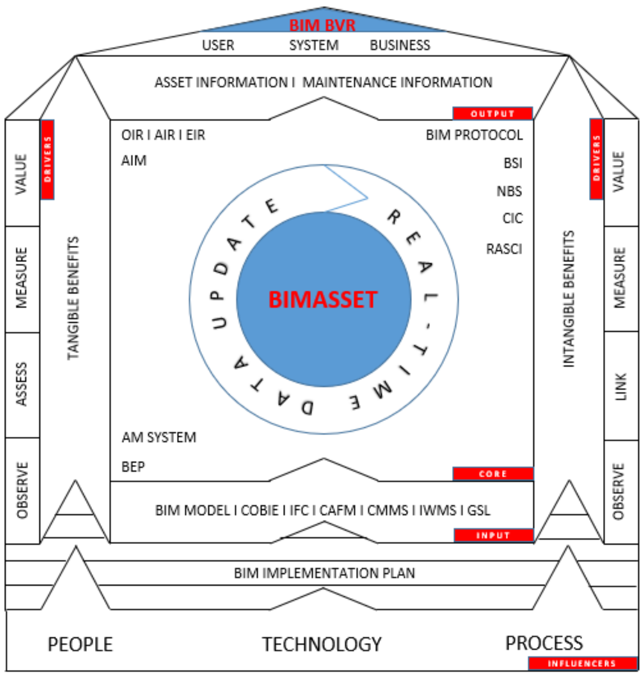

Figure 1: BIM ASSET VR SHUTTLE v3

APPENDIX C4: VERSION 4

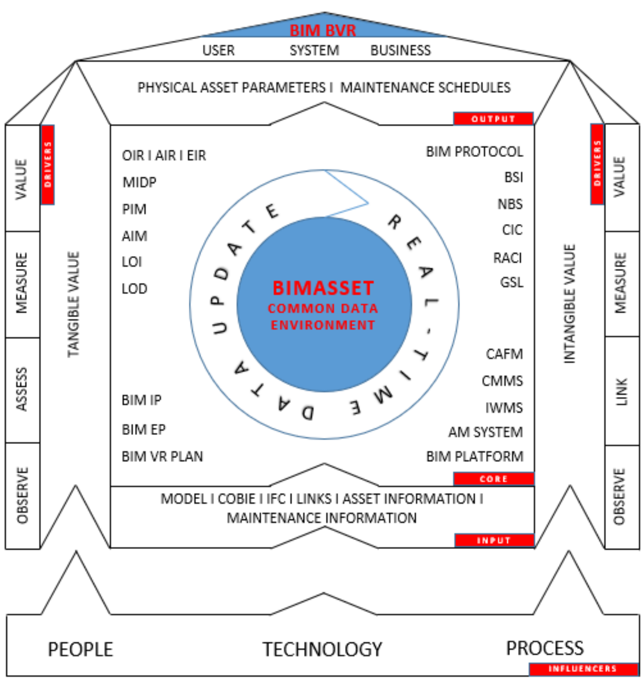

Figure 1: BIM ASSET VR SHUTTLE v4

APPENDIX C5: VERSION 5

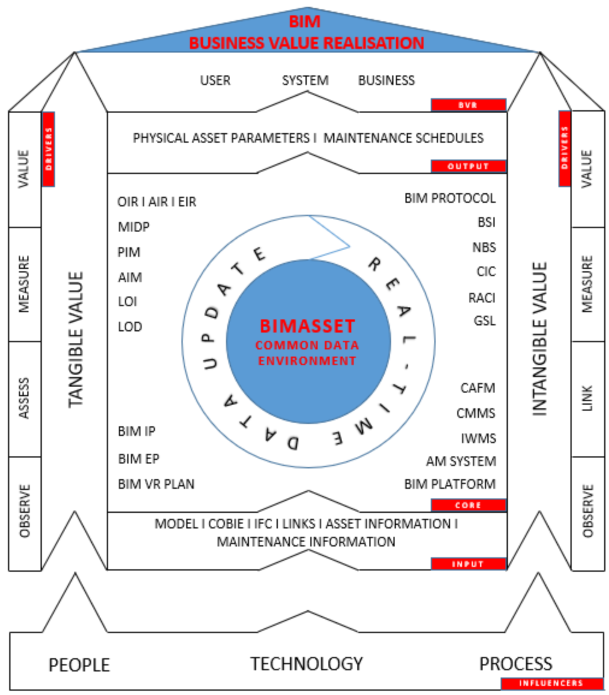

Figure 1: BIMASSET VR SHUTTLE v5

APPENDIX C6: VERSION 6

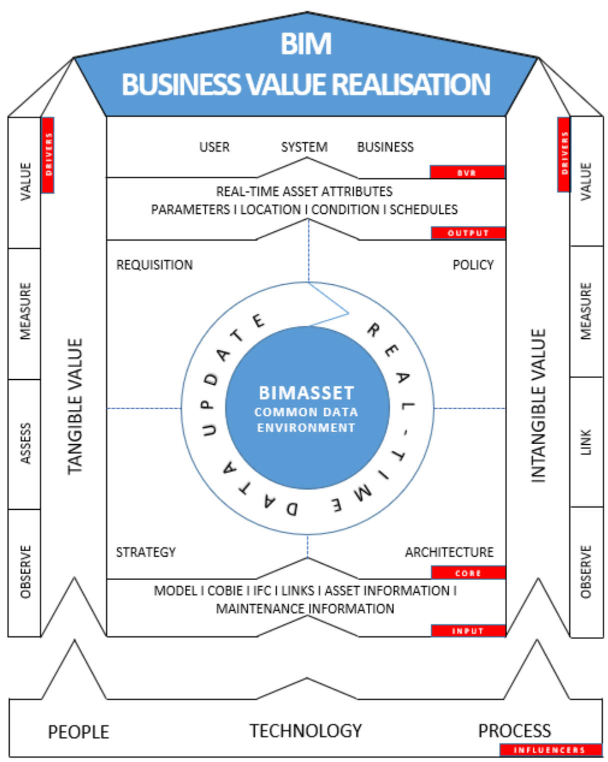

Figure 1: BIMASSET VR SHUTTLE v6

APPENDIX C7: VERSION 7

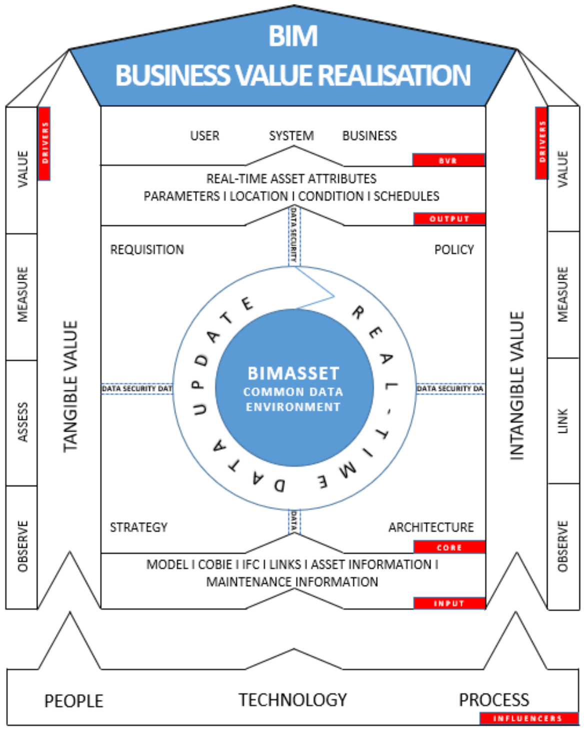

Figure 1: BIMASSET VR SHUTTLE v7

APPENDIX C8: VERSION 8

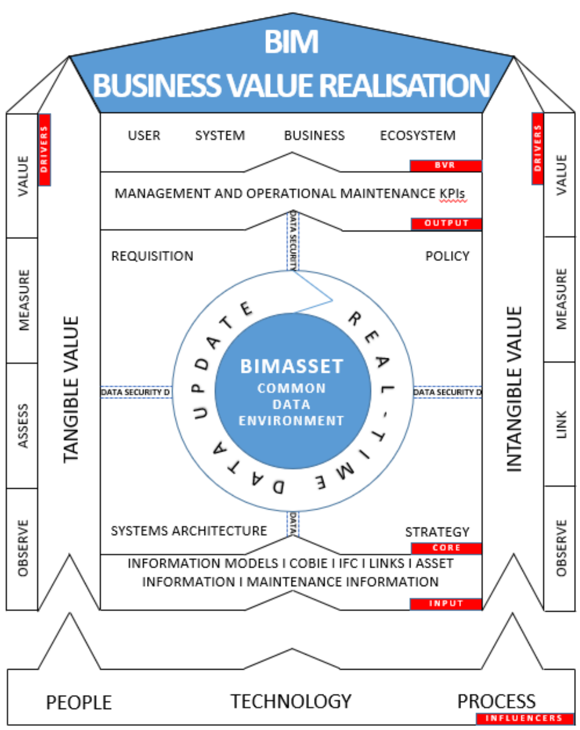

Figure 1: BIMASSET VR SHUTTLE v8

17.0 APPENDIX E: CLASSIFICATION OF AM CLIENTS

APPENDIX E1: IDENTIFIED BUSINESS MODELS

1. **Wholesale and Retail Trade (Section G)**
    a. Retail trade (SG:47)
        i. Retail sale in non-specialised stores (SG:47.1)
        ii. Retail sale of food, beverages and tobacco in specialised stores (SG:47.2)
        iii. Retail sale of automotive fuel in specialised stores (SG:47.3)
        iv. Retail sale of information and communication equipment in specialised stores (SG:47.4)
        v. Retail sale of other household equipment in specialised stores (SG:47.5)
        vi. Retail sale of cultural and recreation goods in specialised stores (SG:47.6)
        vii. Retail sale of other goods in specialised stores (SG:47.7)
2. **Transportation and Storage (Section H)**
    a. Warehousing and support activities for transportation (SH:52)
        i. Warehousing and storage (SH:52.1)
        ii. Support activities for transportation (SF:52.2)
3. **Accommodation and Food Service Activities (Section I)**
    a. Accommodation (SI:55)
        i. Hotels and similar accommodation (SI:55.1)
        ii. Holiday and short-stay accommodation (SI:55.2)
        iii. Camping grounds, recreational vehicle parks and trailer parks (SI:55.3)
4. **Financial and Insurance Activities (Section K)**
    a. Financial service activities, except insurance and pension funding (SK:64.2)
        i. Activities of holding companies (SK:64.20)
        ii. Trusts, funds and similar financial entities (SK:64.3)
5. **Real Estate Activities (Section L)**
    a. Real estate activities (SL:68)
        i. Renting and operating of own or leased real estate (SL:68.2)

6. Professional, Scientific and Technical Activities (M)
    a. Activities of head offices; management consultancy activities
        i. Activities of head offices (SM:70.10)
7. Education (Section P)
    a. Education (SP:85)
8. Human Health and Social Work Activities (Section Q)
    a. Human health activities (SQ:86)
9. Arts, Entertainment and Recreation (Section R)
    a. Creative, arts and entertainment activities (SR:90.0)
        i. Operation of arts facilities (SR:90.04)
    b. Libraries, archives, museums and other cultural activities (SR:91)
        i. Libraries, archives, museums and other cultural activities (SR:91.0)
    c. Sports activities and amusement and recreation activities (SR:93)
        i. Sport activities (SR:93.1)
        ii. Amusement and recreation activities (SR:95.2)

APPENDIX E2: CLASSIFICATION OF AM CLIENTS

CLASSIFICATION OF AM CLIENTS			
SECTION	BUSINESS CLASSIFICATION OF CLIENTS	OWNER-OCCUPIER	RENT/ TENANT
G	Retail sale in non-specialised stores (SG:47.1)	✓	✓
	Retail sale of food, beverages and tobacco in specialised stores (SG:47.2)	✓	✓
	Retail sale of automotive fuel in specialised stores (SG:47.3)	✓	✓
	Retail sale of information and communication equipment in specialised stores (SG:47.4)	✓	✓
	Retail sale of other household equipment in specialised stores (SG:47.5)	✓	✓
	Retail sale of cultural and recreation goods in specialised stores (SG:47.6)	✓	✓
	Retail sale of other goods in specialised stores (SG:47.7)	✓	✓
H	Operation of warehousing and storage facilities for water transport activities of division 50 (SH:52.10/1)	✓	
	Operation of warehousing and storage facilities for air transport activities of division 51 (SH:52.10/2)	✓	
	Operation of warehousing and storage facilities for land transport activities of division 49 (SH:52.10/3)	✓	
	Operation of rail freight terminals (SH:21/1)	✓	
	Operation of rail passenger facilities at railway stations (SH:21/2)	✓	
	Operation of bus and coach passenger facilities at bus and coach stations (SH:21/3)	✓	

CLASSIFICATION OF AM CLIENTS			
SECTION	BUSINESS CLASSIFICATION OF CLIENTS	OWNER-OCCUPIER	RENT/ TENANT
I	Hotels and similar accommodation (SI:55.10)	✓	✓
	Holiday and short-stay accommodation (SI:55.20)	✓	✓
	Holiday centres and villages (SI:55.20/1)	✓	✓
	Youth hostels (SI:55.20/2)	✓	✓
	Other holiday and other short stay accommodation (not including holiday centres and villages or youth hostels) (SI:55.20/9)	✓	✓
	Camping grounds, recreational vehicle parks and trailer parks (SI:55.30)	✓	
	Other accommodation (SI:55.90)	✓	✓
K	Activities of holding companies (SK:64.20)	✓	✓
	Activities of construction holding companies (SK:64.20/3)	✓	✓
	Activities of other holding companies (not including agricultural, production, distribution, and financial services holding companies) (SK:64.20/9)	✓	✓
	Trusts, funds and similar financial entities (SK:64.30)	✓	✓
	Activities of investment trusts (SK:64.30/1)	✓	✓
	Activities of unit trusts (SK:64.30/2)	✓	✓
	Activities of venture and development capital companies (SK:64.30/3)	✓	✓
	Activities of open ended investment companies (SK:64.30/4)	✓	✓
	Activities of property unit trusts (SK:64.30/5)	✓	✓

CLASSIFICATION OF AM CLIENTS			
SECTION	BUSINESS CLASSIFICATION OF CLIENTS	OWNER-OCCUPIER	RENT/ TENANT
	Activities of real estate investment trusts (SK:64.30/6)	✓	✓
L	Renting and operating of own or leased real estate (SL:68.20)		✓
	Renting and operating of Housing Association real estate (SL:68.20/1)		✓
	Letting and operating of conference and exhibition centres (SL:68.20/2)		✓
	Letting and operating of own or leased real estate other than Housing Association real estate and conference and exhibition services) (SL:68.20/9)		✓
M	Activities of head offices (SM:70.10)	✓	✓
P	Operation of education facilities (SP:85)	✓	✓
Q	Operation of human health facilities (SQ:86)	✓	✓
R	Operation of historic sites and buildings and similar visitor attractions (SR:91.03)	✓	
	Operation of sport facilities (SR:93.1)	✓	✓
	Operation of amusement and recreation facilities (SR:93.2)	✓	

18.0 APPENDIX F: SUPPORTED DATA FORMATS

APPENDIX F1: DATA FORMATS

Supported building automation systems (per 1.1.2018), usually no more than 5-year-old systems:

- Arcada
- Atmostech
- BuildingEQ
- Citect
- Cozify
- Computec CSV & XLS
- DEOS
- Siemens Desigo & Desigo Web & EMC
- Egain
- Fidelix
- Honeywell Symmetre & EBI
- Metrix XML (Company A format)
- OBIX
- RFSensit
- Simap
- Schneider Smartstruxure & Vista
- Trend 963
- Visonic

APPENDIX F2: TYPOLOGY OF DATA REQUIRED

For the possible heat recovery and heating & cooling network efficiency calculations:

- Outdoor temperature (°C)
- Supply air temperature after the heat recovery (°C)
- Extract air temperature(°C)
- Depending on the heat recovery type one of the following
- Heat recovery valve position (%)
- Heat recovery damper position (%)
- Rotation speed of the heat recovery wheel (%)
- Temperature measurements from all heating / cooling networks (°C)
- Valve positions from all heating / cooling networks (%)

For the AHU time schedule efficiency:

- Status (on/off) or the rotation speed of the supply air fan (Hz)
- Night ventilation and time lag switch status if available

For the indoor conditions:

- Indoor temperature measurements (°C)
- Indoor humidity measurements (Rh)
- Pressure measurements (Pa)
- Carbon Dioxide measurements (CO2)
- Volatile organic compound measurements (VOC)

APPENDIX F3: REMOTE CONNECTION SPECIFICATIONS

Remote connection specifications:

- Minimum of DSL2 / ADS2L+ connection
- Access to the computer via Teamviewer, VNC, RDP or other remote monitoring software (Company A can provide Teamviewer)
- Access right to Windows admin and the BMS system admin
- Firewall ports opened for ftp data transfer

19.0 APPENDIX G: COMMON REQUIREMENTS ACROSS ALL CASES

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C	NUMBER
1	**Sector**	MEP	Health	Education	
2	**General Classification**				
a.	Attribute or Property Information	●	●		2
b.	BIM Authoring Software Information		●		1
c.	CCS			●	1
d.	Classification System (IFC, Uniclass, OmniClass, SFB, CCS, or ISO)	● (IFC and OmniClass)	● (OmniClass)	● (SfB and CCS)	3
e.	COBie Information	●	●		2
f.	Data Type	●			1
g.	Description		●	●	2
h.	Detailed Content Description	●			1
i.	Documentation Type			●	1
j.	FM Software Information		●		1
k.	Information Location in IFC	●			1
l.	Object, Product or System	●	●	●	3
m.	OmniClass Name	●	●		2
n.	OmniClass Number		●		1
o.	Project Facility Tag			●	1
p.	Scope		●		1
q.	SfB Code Level 1			●	1
r.	SfB Code Level 2			●	1
s.	SfB Code Level 3			●	1
t.	Sourcing Directly from Model or Linked Data			●	1
u.	Subcategory			●	1
v.	Tag Abbreviation			●	1
w.	Trade Model		●		1
x.	Unit (IFC)	●			1
y.	Unit Type	●			1
3	**Standard Description**				
a.	Application	●			1
b.	Building, Object, Product or System Name	●	●	●	3
c.	Created By	●			1
d.	Creation Date	●			1
e.	Level or Storey	●	●		2
f.	Link or Reference to Model	●	●	●	3
g.	System Code or Number	●		●	2
4	**General Description**				
a.	Attribute Name		●		1
b.	Attribute Set		●		1
c.	BIM Authoring Software Data Type		●		1
d.	BIM Authoring Software Parameter Name	●	●		2
e.	BIM Authoring Software Parameter Type	●	●		2
f.	CAD Parameter Name	●			1
g.	CAD Parameter Type	●			1
h.	COBie Field		●		1
i.	COBie Parameter Name		●		1

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C	NUMBER
j.	COBie Parameter Name		●		1
k.	COBie Sheet		●		1
l.	Discipline	●			1
m.	FM Software Attribute		●		1
n.	FM Software Data Type		●		1
o.	FM Software Table		●		1
p.	Permanent Construction ID	●			1
q.	Project Phase	●			1
r.	Property ID	●			1
s.	Shared Parameter Name		●		1
t.	VTJ-PRT	●			1
u.	YTV Use Case	●			1
5	**Location Description**				
a.	Room Name	●			1
b.	Room Number	●			1
c.	Room Type	●			1
d.	Service Area	●			1
e.	Service Area Code	●			1
f.	Service Area Type	●			1
6	**Installation Description**				
a.	Existing Installation	●			1
b.	Installation Date			●	1
c.	Installation Height from Floor	●			1
d.	Installation Height, Abs.	●			1
e.	Installer	●			1
f.	Method of Installation	●			1
g.	Procurement Package	●			1
h.	Special Installation	●			1
i.	Supplier	●		●	2
7	**Product Description**				
a.	Asset ID, Object ID or System ID	●	●		2
b.	ETIM-Class	●			1
c.	Group Code	●			1
d.	GTIN Code	●			1
e.	GUID	●			1
f.	Life Expectancy			●	1
g.	LOD	●	●		2
h.	LOG	●			1
i.	LOI	●			1
j.	Manufacturer or Producer	●	●	●	3
k.	Manufacturer URL	●			1
l.	Model Number, Model Type or Product Series	●	●	●	3
m.	Note or Comments	●	●	●	3
n.	Object Group ID	●			1
o.	Object Type	●			1
p.	Position	●			1
q.	Product Description	●			1
r.	Product Name	●			1
s.	Product Number	●	●		2
t.	Running Index	●			1
u.	Sensor GUID	●			1
v.	Sensor ID	●			1

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C	NUMBER
w.	Sensor Measure Origin	●			1
x.	Sensor Type	●			1
y.	Status	●			1
z.	Unit Tag			●	1
aa.	URL	●			1
ab.	Warranty Start Date			●	1
8	**Technical Description**				
a.	Actual Volume Flow Setpoint	●			1
b.	Actuator	●			1
c.	Air Tank National Board Number		●		1
d.	Angle	●			1
e.	Colour	●			1
f.	Colour Code	●			1
g.	Colour Temperature	●			1
h.	Connection Size	●			1
i.	Control Address	●			1
j.	Control Unit	●			1
k.	Degree of Protection (IP)	●			1
l.	Delivered Air Capacity		●		1
m.	Design Pressure Loss	●			1
n.	Design Pressure Static	●			1
o.	Design Sound Level	●			1
p.	Design Volume Flow	●			1
q.	Design Volume Flow Setpoint	●			1
r.	Dimensions or Size		●		1
s.	Electric Current	●	●		2
t.	Enclosure Type		●		1
u.	Frame		●		1
v.	Hertz		●		1
w.	Horsepower		●		1
x.	K-factor	●			1
y.	Kv-value	●			1
z.	Lamp Power	●			1
aa.	Lamp Type	●			1
ab.	Luminaire Power	●			1
ac.	Luminous Flux	●			1
ad.	Material	●			1
ae.	Maximum Airflow		●		1
af.	Measured Pressure	●			1
ag.	Measured Pressure Loss	●			1
ah.	Measured Sound Level	●			1
ai.	Measured Volume Flow	●			1
aj.	Minimum Airflow		●		1
ak.	Number of Objects or Systems	●	●		2
al.	Phase		●		1
am.	Power	●			1
an.	Reheat Coil Capacity		●		1
ao.	Reheat Coil Waterflow (GPM)		●		1
ap.	RPM		●		1
aq.	Service Factor		●		1
ar.	Typical Flow Rate or Airflow	●	●		2
as.	Velocity	●			1
at.	Voltage	●	●		2

S/NO	THEMES	COMPANY A	COMPANY B	COMPANY C	NUMBER
9	**Physical Description**				
a.	Gross Floor Area	●			1
b.	Height	●			1
c.	Length	●			1
d.	Maintenance Space	●			1
e.	Net Floor Area	●			1
f.	Thickness	●			1
g.	Volume	●			1
h.	Weight	●			1
i.	Width	●			1
10	**Model Reference**				
a.	Active or Passive Fire System			●	1
b.	Balcony Type			●	1
c.	Ceiling (removable?)			●	1
d.	Ceiling Type			●	1
e.	Colour (RAL / NCS)			●	1
f.	D-Value			●	1
g.	Fire Classification (REI)			●	1
h.	Floor Type			●	1
i.	FM Software Data Requirement Reference		●		1
j.	Inside or Outside?			●	1
k.	Located in Project or Facility?		●		1
l.	Location			●	1
m.	Material			●	1
n.	Modelled?		●		1
o.	Movable?			●	1
p.	Notes on Accessibility			●	1
q.	Number or Quantity			●	1
r.	Static System?			●	1
s.	Surface			●	1
t.	System, Object or Product Tagged Individually in Model?		●		1
u.	Trade Model		●		1

KEY:

Requirement Common in All 3 Cases

Requirement Common in 2 Cases

Requirement Common in 1 Case Only

20.0 APPENDIX H: COMPANY A

APPENDIX H1: INFORMATION

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This table standardizes the data generated by the construction project as a property field and as part of their potential values

Principles for using the table:

- The data fields are not limited to the content of IFC files. Propertits can come from some other system, from linked databases,
- all properties are not expected to be completed in the YTV2012 construction project.
- one party is not expected to produce any property information. There are several producers of information
- The "Standard Table" tab should be context-specific. By default, the requirement content according to YTV2012 is assumed.
- The purpose of the table is to allow for the ability to make the structure so that the context of the property is both written and known to the reader
- Use of the Selection List is desirable in order to extend the interpretation of information in readable software. The content of the Selection List fields can be sent to the undersigned
- Standardization of data content is made using English-language properties

APPENDIX H2: PROPERTIES

IFC TARGET FOR ANY OBJECTIVE	PROPERTY	FINNISH EQUIVALENT	INFORMATION LOCATION IN IFC	UNIT TYPE	UNIT (HALUTTU)	UNIT (IFC)	DATA TYPE	HVAC	ELECTRICAL	DETAILED EXPLANATION OF THE CONTENT
IFC-standard	Application	Sovellus					Text	MagiCAD HPV 2015.4	CADS Electric 17	Native version
IFC-standard	Created By	Yritys					Text	Sweco Building Services	Granlund	An IFC file company
IFC-standard	Creation Date	Luontipäivämäärä					Date	05/05/2016	05/05/2016	Date IFC to make a file
IFC-standard	Storey	Kerros	IfcBuildingStorey (Name)				Text	1st floor	1st floor	The floor where the object is located
IFC-standard	System Code	Järjestelmän tunnus	IfcSystem (Description)				Text	301	W21	Identification code used for systems used
IFC-standard	System Name	Järjestelmän nimi	IfcSystem (Name)				Text	Offices, part A	normal Distribution	The name used for the coding method used for systems
IfcSystem	Discipline	Tekniikanala	bSF_General				Selection list	Ventilation	Electrical	The name of the design industry, use the "Selection List" options
IfcBuilding	Permanent Construction ID	Rakennustunnus	bSF_General				Text	17302	17302	Real Estate Owner's Real Estate Code, RATU etc.
IfcBuilding	Project Phase	Suunnitteluvaihe	bSF_General				Selection list	General Design	implementation Planning	Design phase name
IfcBuilding	Property ID	Kiinteistötunnus	bSF_General				Text			Designer Real Estate ID
IfcBuilding	VTJ-PRT	Pysyvä rakennustunnus	bSF_General				Text	101485717T	101485717T	The permanent building code of the demographic information system
Location	Room Name	Tilanimi	bSF_Location				Text	IV Machine room	IV Machine room	Settling must be an architectural model
	Room Number	Tilanumero	bSF_Location				Text	1001	1001	The number must be an architectural model
	Room Type	Tilatyyppi	bSF_Location				Text	Technical condition	Technical condition	The type of facility where the object is, eg "Offices, 2 persons" etc.
	Service Area	Palvelualue	bSF_Location				Text	Offices, Part A	Block C	System Service Area
	Service Area Code	Palvelualuetunnus	bSF_Location				Text	301	W21	System Service Area Id
	Service Area Type	Palvelualueen tyyppi	bSF_Location				Text	Hospital Gases	Distribution Units	Type of Service Area
Installation	Existing Installation	Olemassa oleva asennus	bSF_Installation				Selection list	Well	Well	Whether it's an existing installation or a new one
	Install	Asentaa	bSF_Installation				Selection list	PU	SU	A contractor who installs a device or accessory
	Installation Height From Floor	Asennuskorko lattiasta	bSF_Installation	Length	mm	m	Number	3500	3500	To the center line of the installation
	Installation Height, Abs.	Asennuskorko, abs.	bSF_Installation	Length	m	m	Number	35.55	35.55	To the center line of the installation
	Method Of Installation	Asennustapa	bSF_Installation				Text		Surface	Eg surface, sink, suspension rail
	Procurement Package	Hankintapaketti	bSF_Installation				Text	MRU2	Tele3	For example, project package purchase information package or similar.
	Special Installation	Erikoisasennus	bSF_Installation				Boolean	TRUE / FALSE	TRUE / FALSE	As a driver, it's a special thing that matters for example in Pricing
	Supplier	Toimittaa	bSF_Installation				Selection list	AU	SU	Contractor who supplies equipment or supplies
Product	ETIM-class	ETIM-luokka	bSF_Product				Text	EC010351	EC001957	ETIM class code, TT060
	Group Code	Tuoteryhmä	bSF_Product				Text	83 Setting / closing dams	42 Public lighting fixtures	According to the nomenclature
	GTIN Code	GTIN koodi	bSF_Product				Number	6415883817050	6438045014326	GTIN code, TT052
	GUID	GUID	bSF_Product				Text	iIggFrkxdJS652KC: His	iIggFrkx52KC: His	Unique identifier of the object
	LOD	LOD	bSF_Product				Number	400	400	Level Of Development. Combined geometry and data content requirement
	LOG	LOG	bSF_Product				Number	300	300	Level of Geometry. Geometry Requirement Definition
	LOI	LOI	bSF_Product				Number	350	350	Level of Information. Information requirement definition
	Manufacturer	Valmistaja	bSF_Product				Text	Halton	Teknoware	Product manufacturer. Product Data Standard Field TT110
	Manufacturer URL	Laitevalmistajan linkki	bSF_Product				Link	https://www.halton.com	http://www.teknoware.co	Link to eg the equipment manufacturer's product brochure, TT731
	Note	Kommenttikenttä	bSF_Product				Text	something 3	something 3	For comments
	Object Group ID	Laitetunnustyyppi	bSF_Product				Text	IMS2		Device Type ID
	Object ID	Yksilöllinen laitetunnus	bSF_Product				Text	301IMS1001.01		Individual ID
	Object Type	Objektin tyyppi	bSF_Product				Selection list	damper	signaling lamp	Type object. Product Data Standard Field TT200, Common Name
	Position	Positio	bSF_Product				Text		1.1	The position of the device in a luminaire, for example
	Product Description	Tuoteen tarkenne	bSF_Product				Text		1 h with supercondensor	Product Specification, Long Product Name, TT202
	Product Name	Tuotenimi	bSF_Product				Text	UTT/C 315 CT=D2	Y9092WM120 230VAC 25	Product name, eg Product Data Standard Field TT201
	Product Number	Tuotenumero	bSF_Product				Text	8381705	4281251	Eg HVAC number (TT020), Electrical number (TT010), Vendor product code (TT050)
	Product Serie	Tuotesarja	bSF_Product				Text	UTT	Guide 90	Product Data Standard Field TT120
	Running Index	Juokseva numero	bSF_Product				Text	2	3	Running number or text
	Status	Status	bSF_Product				Selection list			Potential status of the product
	URL	Linkki	bSF_Product				Link		http://www...	For example: http://www.sahkonumerot.fi/[sähkönumero] or http://www.lvi-

IFC TARGET FOR ANY OBJECTIVE	PROPERTY	FINNISH EQUIVALENT	INFORMATION LOCATION IN IFC	UNIT TYPE	UNIT (HALUTTU)	UNIT (IFC)	DATA TYPE	HVAC	ELECTRICAL	DETAILED EXPLANATION OF THE CONTENT
Technical	Actual Volume Flow setpoint	Esisäätö, todellinen	bSF_Technical				Number	6		Adjusted, real pre-adjustment
	Colour	Väri	bSF_Technical				Text			White
	Colour Code	Väritunnus	bSF_Technical				Text			RAL9010
	Colour Temperature	Värilämpötila	bSF_Technical	Thermodynamic temperature	K	K	Number		4000	Lamp color temperature
	Control Address	Ohjauskohde	bSF_Technical				Text		@2	The control object, eg in the DALI lamp, is useful in maintaining the DALI address
	Control Unit	Ohjauskeskus	bSF_Technical				Text	VAK	JK 2.2	Whether the device is controlled via automation or whether it is operating
	Current	Virta	bSF_Technical	Electric current	A	A	Number		35	
	Degree of protection (IP)	Suojausluokka	bSF_Technical				Text		20	Protection class
	Design Pressure Static	Laskettu staattinen painetaso	bSF_Technical	Pressure	Pa / kPa	Pa	Number	250		Calculated static pressure level, in conjunction with IV desired unit Pa, for pipelines kPa
	Design Pressure Loss	Laskettu painehäviö	bSF_Technical	Pressure	Pa / kPa	Pa	Number	15		Calculated pressure loss, in conjunction with IV the desired unit Pa, for pipelines kPa
	Design Sound Level	Äänitaso, laskettu	bSF_Technical	Sound pressure level	dB	dB	Number	33		Sound level
	Design Volume Flow	Tilavuusvirta	bSF_Technical	Volumetric flow rate	dm3/s	m3/s	Number	1.2		Volume flow, dm3 / s
	Design Volume Flow setpoint	Esisäätö, laskettu	bSF_Technical				Number	5.5		presetting
	Diameter DN	DN-koko	bSF_Technical				Text	25		DN size
	K-factor	K-arvo	bSF_Technical				Number			K-value
	Lamp Power	Lampun teho	bSF_Technical	Power	W	W	Number		35	The power of a single lamp
	Lamp Type	Lampputyyppi	bSF_Technical				Text		LED	
	Luminaire Power	Valaisimen konaisteho	bSF_Technical	Power	W	W	Number		70	Total power of the lamps connected to the lamp
	Luminous flux	Lumen -arvo	bSF_Technical	Luminous flux	lm	lm	Number		1100	The lumen value from the luminaire
	Material	Materiaali	bSF_Technical				Text	Cu	Al	Material
	Measured Pressure	Mitattu painetaso	bSF_Technical	Pressure	Pa / kPa	Pa	Number	248		Measured pressure level, in conjunction with IV required unit Pa, for pipelines kPa
	Measured Pressure Loss	Mitattu painehäviö	bSF_Technical	Pressure	Pa / kPa	Pa	Number	17		Measured pressure loss, in conjunction with IV the desired unit Pa, for pipelines kPa
	Measured Sound Level	Äänitaso, mitattu	bSF_Technical	Sound pressure level	dB	dB	Number	31		Sound level
	Measured Volume Flow	Mitattu tilavuusvirta	bSF_Technical	Volumetric flow rate	dm3/s	m3/s	Number	1.1		Measured actual fluid flow
	Number Of Lamps	Lamppumäärä	bSF_Technical				Number		3	Number of lamp lamps
	Power	Teho	bSF_Technical	Power	kW	W	Number	100		Power, kW
	Typical Flow Rate	Normivirta	bSF_Technical	Volumetric flow rate	dm3/s	m3/s	Number	0.2		Normal flow, dm3 / s
	Velocity	Nopeus	bSF_Technical	Velocity	m/s	m/s	Number	1.8		Speed on face, channel ...
	Voltage	Jännite	bSF_Technical	Electric potential	V	V	Number	400		
Physical	Length	Pituus	bSF_Physical	Length	mm	m	Number	1000	1000	Length of space, product, pipe, channel, cable tray, etc.
	Gross Floor Area	Pinta-ala, brutto	bSF_Physical	Area	m2	m2	Number	25	25	Gross area of space or product
	Height	Korkeus	bSF_Physical	Length	mm	m	Number	1000	1000	Height of the space, product, pipe, duct, cable tray, etc. ...
	Maintenance Space	Huoltotila	bSF_Physical	Length	mm	m	Number	800	1200	Required service space around the unit
	Net Floor Area	Pinta-ala, netto	bSF_Physical	Area	m2	m2	Number	3	3	Net area of a holding or product
	Thickness	Paksuus	bSF_Physical	Length	mm	m	Number	3	3	For example, pipe wall insulation, insulation thickness etc.
	Weight	Paino	bSF_Physical	Mass	kg	g	Number	2	2	Product weight
	Width	Leveys	bSF_Physical	Length	mm	m	Number	1000	1000	The width of the space, product, pipe, channel, cable tray, etc .... The circular diameter
	Volume	Tilavuus	bSF_Physical	Volume	m3	m3	Number	10	10	Volume, product, pipe, channel, etc ... volume. Pipes / channels = interior volume

APPENDIX B3: OBJECTS

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OBJECT CATEGORY	OBJECT	OBJECT CATEGORY	OBJECT	OBJECT CATEGORY	OBJECT	OBJECT CATEGORY	OBJECT
Pipes	Pipelines	Electrical	Transformers	Ventilation	The ducts	Building automation	RAU-centers
	Heat insulation for pipes		Switchgear		Ductwork insulation		Measurement Sensors
	Shut-off valves		Main switchboards		IV machines, ventilation blower		Adjustment and other enclosures
	Pre-adjustable valves		Busbar-Automatic power products		The diffuser		Actuators
	Engine Valves		Compatible backup chargers		Louvres		
	Other valves		The batteries		The terminals		
	Air eliminators		Distribution Units		Mounting air grille		
	Filters		Cross-connection Racks		Dampers		
	Flexible connectors		Central telecommunications systems		Air / DC Current Controllers		
	Safety valve		Central control systems for security systems		Fire, smoke control, etc		
	Expansion vessels		Cable shelves and hanging rails		Channel silencers		
	Heat exchangers		Cable management		Maintenance doors		
	Heat Distribution Centers		Floor channels and boxes		IV-duct system radiators		
	Water-cooled machines		Profiles and hangings		Other Channel Components		
	Other main machines		Fixtures		Flexible connectors		
	Liquid Tanks		Poistumisvalaisimet		Brackets		
	Manifolds		Emergency and safety lights		Sensors (TI, PE, PDE, etc.)		
	Underfloor heating pipes		Switches				
	Radiators and Convectors		Sockets				
	Convection machines		Motion and presence sensors				
	IV-duct system radiators		Safety switches				
	Hot water Furniture		Sharing and junction boxes				
	Washbasins and the like		Tannoy				
	Quick Fire hydrants		Cameras				
	Drains		Smoke detector				
	A fire protection sleeve		Fire buttons				
	Floor drains		Signaling				
	Roof drains		Sensors and actuators				
	Rainwater and waste water		Telecommunications Outlet				
	Separation holes (HEK, REK etc)		Riser pipes				
	Inspection tubes and holes		Tele Body Wires				
	Wastewater and wastewater pumping stations		Cabling of electrical points				
	Sensors (TI, PE, PDE, etc.)		Cabling of telephones				
	Pipe supports		Cabling of security systems				
	Sprinklers		Inverters				

APPENDIX H3: STANDARDISATION TABLE

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Intended use: YTV2012 information content according to implementation design

PIPES

PROPERTYSET	PROPERTY	IFC- File Information	Pipelines	Heat insulation for pipes	Shut-off valves	Pre-adjustable valves	Engine Valves	Other valves	Air eliminators	Filters	Flexible connectors	Safety valve	Expansion vessels	Heat exchangers	Heat Distribution Centers	Water-cooled machines	Other main machines	Liquid Tanks	Manifolds	Underfloor heating pipes	Radiators and Convectors	Convection machines	Hot water Furniture	Washbasins and the like	Quick Fire hydrants	Drains	A fire protection sleeve	Floor drains	Roof drains	Rainwater and waste water	Separation holes (HEK, REK etc)	Inspection tubes and holes	Wastewater and wastewater pumping	Sensors (TI, PE, PDE, etc.)	Pipe supports	Sprinklers
IFC standard	Application	x																																		
	Created By	x																																		
	Creation Date	x																																		
	Storey		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Code		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Name		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GENERAL	Discipline		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Permanent Construction ID	x																																		
	Project Phase		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Property ID	x																																		
	VTJ-PRT	x																																		
LOCATION	Room Name																																			
	Room Number																																			
	Room Type																																			
	Service Area																																			
	Service Area Code																																			
	Service Area Type																																			
INSTALLATION	Existing Installation																																			
	Install																																			
	Installation Height From Floor																																			
	Installation Height, Abs.																																			
	Method Of Installation																																			
	Procurement Package																																			
	Special Installation																																			
	Supplier																																			
PRODUCT	ETIM-class																																			
	Group Code																																			
	GTIN Code																																			
	GUID																																			
	LOD																																			
	LOG																																			
	LOI																																			
	Manufacturer																																			
	Manufacturer URL																																			
	Note																																			
	Object Group ID					x	x		x	x		x		x	x	x	x		x				x		x		x	x	x							x
	Object ID																					x														
	Object Type			x																																
	Position																																			
	Product Description																																			
	Product Name				x	x															x		x		x			x								
	Product Number																																			
	Product Serie																																			
	Running Index																																			
	Status																																			
	URL																																			

VENTILATION

PROPERTYSET	PROPERTY	The ducts	Ductwork insulation	IV machines, ventilation blower	The diffuser	Louvres	The terminals	Mounting air grille	Dampers	Air / DC Current Controllers	Fire, smoke control, etc	Channel silencers	Maintenance doors	IV-duct system radiators	Other Channel Components	Flexible connectors	Brackets	Sensors (TI, PE, PDE, etc.)
IFC standard	Application																	
	Created By																	
	Creation Date																	
	Storey	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Code	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Name	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GENERAL	Discipline	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Permanent Construction ID																	
	Project Phase	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Property ID																	
	VTJ-PRT																	
LOCATION	Room Name																	
	Room Number																	
	Room Type																	
	Service Area																	
	Service Area Code																	
	Service Area Type																	
INSTALLATION	Existing Installation																	
	Install																	
	Installation Height From Floor																	
	Installation Height, Abs.																	
	Method Of Installation																	
	Procurement Package																	
	Special Installation																	
	Supplier																	
PRODUCT	ETIM-class																	
	Group Code																	
	GTIN Code																	
	GUID																	
	LOD																	
	LOG																	
	LOI																	
	Manufacturer																	
	Manufacturer URL																	
	Note																	
	Object Group ID				x	x	x	x	x		x	x	x	x		x		
	Object ID			x						x					x			
	Object Type		x															
	Position																	
	Product Description																	
	Product Name						x	x	x	x	x	x						
	Product Number																	
	Product Serie																	
	Running Index																	
	Status																	
	URL																	

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Intended use: YTV2012 information content according to implementation design

PIPES

PROPERTYSET	PROPERTY	IFC- File information	Pipelines	Heat insulation for pipes	Shut-off valves	Pre-adjustable valves	Engine Valves	Other valves	Air eliminators	Filters	Flexible connectors	Safety valve	Expansion vessels	Heat exchangers	Heat Distribution Centers	Water-cooled machines	Other main machines	Liquid Tanks	Manifolds	Underfloor heating pipes	Radiators and Convectors	Convection machines	Hot water Furniture	Washbasins and the like	Quick Fire hydrants	Drains	A fire protection sleeve	Floor drains	Roof drains	Rainwater and waste water	Separation holes (HEK, REK etc)	Inspection tubes and holes	Wastewater and wastewater pumping	Sensors (TI, PE, PDE, etc.)	Pipe supports	Sprinklers
TECHNICAL	Actual Volume Flow setpoint																																			
	Colour																																			
	Colour Code																																			
	Colour Temperature																																			
	Control Address																																			
	Control Unit																																			
	Current																																			
	Degree of protection (IP)																																			
	Design Pressure Static		x																	x																
	Design Pressure Loss				x	x	x	x						x	x	x						x	x		x											
	Design Sound Level																																			
	Design Volume Flow		x				x							x	x	x				x		x														
	Design Volume Flow setpoint					x																														
	Diameter DN		x		x	x	x	x	x	x	x	x								x						x	x	x	x							x
	K-factor																																			x
	Lamp Power																																			
	Lamp Type																																			
	Luminaire Power																																			
	Luminous flux																																			
	Material		x																	x						x										
	Measured Pressure																																			
	Measured Pressure Loss																																			
	Measured Sound Level																																			
	Measured Volume Flow																																			
	Number Of Lamps																																			
	Power													x	x	x					x	x														
	Typical Flow Rate																						x		x			x								
	Velocity																																			
	Voltage																																			
PHYSICAL	Length																																			
	Gross Floor Area																																			
	Height																																			
	Maintenance Space																																			
	Net Floor Area																																			
	Thickness			x																																
	Weight																																			
	Width																																			
	Volume												x					x																		

VENTILATION

PROPERTYSET	PROPERTY	The ducts	Ductwork insulation	IV machines, ventilation blower	The diffuser	Louvres	The terminals	Mounting air grille	Dampers	Air / DC Current Controllers	Fire, smoke control, etc	Channel silencers	Maintenance doors	IV-duct system radiators	Other Channel Components	Flexible connectors	Brackets	Sensors (TI, PE, PDE, etc.)
TECHNICAL	Actual Volume Flow setpoint																	
	Colour																	
	Colour Code																	
	Colour Temperature																	
	Control Address																	
	Control Unit																	
	Current																	
	Degree of protection (IP)																	
	Design Pressure Static	x																
	Design Pressure Loss						x		x	x	x	x						
	Design Sound Level						x		x									
	Design Volume Flow	x					x		x	x		x						
	Design Volume Flow setpoint						x		x									
	Diameter DN	x		x			x	x	x	x	x							
	K-factor																	
	Lamp Power																	
	Lamp Type																	
	Luminaire Power																	
	Luminous flux																	
	Material	x																
	Measured Pressure																	
	Measured Pressure Loss																	
	Measured Sound Level																	
	Measured Volume Flow																	
	Number Of Lamps																	
	Power																	
	Typical Flow Rate																	
	Velocity																	
	Voltage																	
PHYSICAL	Length			x			x	x				x		x	x			
	Gross Floor Area																	
	Height			x										x	x			
	Maintenance Space																	
	Net Floor Area																	
	Thickness		x															
	Weight																	
	Width			x			x	x						x	x			
	Volume																	

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Intended use: YTV2012 information content according to implementation design

	PROPERTYSET / PROPERTY: IFC- File Information	MagiCAD	CADS
PIPES			
	Pipelines	IfcPipeSegmentType	IFCFLOWSEGMENT, PipeSegmentType
	Heat insulation for pipes	IfcPipeSegmentType	IFCFLOWSEGMENT, PipeSegmentType
	Shut-off valves	IfcCovering	
	Pre-adjustable valves	IfcValveType	IFCFLOWCONTROLLER, ValveType
	Engine Valves	IfcValveType	IFCFLOWCONTROLLER, ValveType
	Other valves	IfcValveType	IFCFLOWCONTROLLER, ValveType
	Air eliminators	IfcFlowController	IFCFLOWTERMINAL, AirTeminalType
	Filters	IfcFilter	IFCFLOWTREATMENTDEVICE,FlowTerminalTreatmentDevice Tvpe
	Flexible connectors		
	Safety valve	IfcValveType	IFCFLOWCONTROLLER, ValveType
	Expansion vessels	IfcTank	IFCFLOWSTORAGEDEVICE, TankType
	Heat exchangers	IfcHeatExchangerType	
	Heat Distribution Centers	IfcHeatExchangerType	
	Water-cooled machines		
	Other main machines	IfcFlowTerminal / IfcHeatExchangerTvpe	
	Liquid Tanks	IfcTank	IFCFLOWSTORAGEDEVICE, TankType
	Manifolds	IfcFlowController	IFCFLOWFITTING, PipeFittingType
	Underfloor heating pipes	IfcPipeSegmentType	IFCFLOWSEGMENT, PipeSegmentType
	Radiators and Convectors	IfcSpaceHeaterType	IFCFLOWTERMINAL, SpaceHeaterType
	Convection machines	IfcCoilType	
	Hot water Furniture	IfcSanitaryTerminalType	
	Washbasins and the like	IfcSanitaryTerminalType IfcWasteTerminalTvpe	
	Quick Fire hydrants	IfcFireSuppressionTerminalType	
	Drains	IfcPipeSegmentType	IFCFLOWSEGMENT,PipeSegmentType
	A fire protection sleeve	IfcFlowController	
	Floor drains	IfcWasteTerminalType	IFCFLOWSEGMENT,PipeSegmentType
	Roof drains	IfcWasteTerminalType	
	Rainwater and waste water	IfcWasteTerminalType	
	Separation holes (HEK, REK etc)	IfcWasteTerminalType	
	Inspection tubes and holes	IfcWasteTerminalType	
	Wastewater and wastewater pumping	IfcWasteTerminalType	
	Sensors (TI, PE, PDE, etc.)	IfcWasteTerminalType	
	Pipe supports	IfcWasteTerminalType	
	Sprinklers	IfcFireSuppressionTerminalType	
VENTILATION			
	The ducts	IfcDuctSegmentType	IFCFLOWSEGMENT, DuctSegmentType
	Ductwork insulation	IfcCovering	
	IV machines, ventilation blower	IfcFanType	IFCFLOWMOVINGDEVICE, FanType
	The diffuser	IfcAirTerminalType	IFCFLOWTERMINAL, AirTerminalType
	Louvres	IfcAirTerminalType	IFCFLOWFITTING,DuctfittingType
	The terminals	IfcAirTerminalType	IFCFLOWTERMINAL, AirTerminalType
	Mounting air grille	IfcAirTerminalType	
	Dampers	IfcDamperType	IFCFLOWCONTROLLER, DamperType
	Air / DC Current Controllers	IfcDamperType	
	Fire, smoke control, etc	IfcDamperType (predefinedtype = FIREDAMPER)	IFCFLOWCONTROLLER, DamperType
	Channel silencers	IfcDuctSilencerType	IFCFLOWTREATMENTDEVICE, DuctSilencerType
	Maintenance doors	IfcDuctFittingType	
	IV-duct system radiators	IfcCoilType	
	Other Channel Components	IfcHumidifierType / IfcFilterType	
	Flexible connectors		
	Brackets	IfcFlowController / IfcElectricalApplianceTvpe	
	Sensors (TI, PE, PDE, etc.)		

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PROPERTYSET	PROPERTY	IFC- File Information	ELECTRICAL																																			BUILDING AUTOMATION			
			Transformers	Switchgear	Main switchboards	Busbar-Automatic power products	Compatible backup chargers	The batteries	Distribution Units	Cross-connection Racks	Central telecommunications	Central control systems for security systems	Cable shelves and hanging rails	Cable management	Floor channels and boxes	Profiles and hangings	Fixtures	Poistumisvalaisimet	Emergency and safety lights	Switches	Sockets	Motion and presence sensors	Safety switches	Sharing and junction boxes	Tannoy	Cameras	Smoke detector	Fire buttons	Signaling	Sensors and actuators	Telecommunications Outlet	Riser pipes	Tele Body Wires	Cabling of electrical points	Cabling of telephones	Cabling of security systems	Inverters	RAU-centers	Measurement Sensors	Adjustment and other enclosures	Actuators
IFC standard	Application	x																																							
	Created By	x																																							
	Creation Date	x																																							
	Storey		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Code		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	System Name		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GENERAL	Discipline		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Permanent Construction ID	x																																							
	Project Phase		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Property ID	x																																							
	VTJ-PRT	x																																							
LOCATION	Room Name																																								
	Room Number																																								
	Room Type																																								
	Service Area																																								
	Service Area Code																																								
	Service Area Type																																								
INSTALLATION	Existing Installation																																								
	Install																																								
	Installation Height From Floor																																								
	Installation Height, Abs.																																								
	Method Of Installation																																								
	Procurement Package																																								
	Special Installation																																								
	Supplier																																								
PRODUCT	ETIM-class																																								
	Group Code																																								
	GTIN Code																																								
	GUID																																								
	LOD																																								
	LOG																																								
	LOI																																								
	Manufacturer																																								
	Manufacturer URL																																								
	Note																																								
	Object Group ID		x	x	x		x	x	x	x	x	x										x									x						x	x	x	x	x
	Object ID																																								
	Object Type												x							x	x		x		x	x	x	x	x	x	x										
	Position																x	x	x																						
	Product Description																																								
	Product Name																																								
	Product Number																																								
	Product Serie																																								
	Running Index																																								
	Status																																								
	URL																																								

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			ELECTRICAL												
PROPERTYSET	PROPERTY	IFC- File Information	Transformers	Switchgear	Main switchboards	Busbar-Automatic power products	Compatible backup chargers	The batteries	Distribution Units	Cross-connection Racks	Central telecommunications	Central control systems for security systems	Cable shelves and hanging rails	Cable management	Floor channels and boxes
TECHNICAL	Actual Volume Flow setpoint														
	Colour														
	Colour Code														
	Colour Temperature														
	Control Address														
	Control Unit														
	Current														
	Degree of protection (IP)														
	Design Pressure Static														
	Design Pressure Loss														
	Design Sound Level														
	Design Volume Flow														
	Design Volume Flow setpoint														
	Diameter DN														
	K-factor														
	Lamp Power														
	Lamp Type														
	Luminaire Power														
	Luminous flux														
	Material														
	Measured Pressure														
	Measured Pressure Loss														
	Measured Sound Level														
	Measured Volume Flow														
	Number Of Lamps														
	Power														
	Typical Flow Rate														
	Velocity														
	Voltage														
PHYSICAL	Length														x
	Gross Floor Area														
	Height					x							x	x	x
	Maintenance Space														
	Net Floor Area														
	Thickness														
	Weight														
	Width					x							x	x	x
	Volume														

		ELECTRICAL												
PROPERTYSET	PROPERTY	Profiles and hangings	Fixtures	Poistumisvalaisimet	Emergency and safety lights	Switches	Sockets	Motion and presence sensors	Safety switches	Sharing and junction boxes	Tannoy	Cameras	Smoke detector	Fire buttons
TECHNICAL	Actual Volume Flow setpoint													
	Colour													
	Colour Code													
	Colour Temperature													
	Control Address												x	x
	Control Unit													
	Current													
	Degree of protection (IP)													
	Design Pressure Static													
	Design Pressure Loss													
	Design Sound Level													
	Design Volume Flow													
	Design Volume Flow setpoint													
	Diameter DN													
	K-factor													
	Lamp Power													
	Lamp Type													
	Luminaire Power													
	Luminous flux													
	Material													
	Measured Pressure													
	Measured Pressure Loss													
	Measured Sound Level													
	Measured Volume Flow													
	Number Of Lamps													
	Power													
	Typical Flow Rate													
	Velocity													
	Voltage													
PHYSICAL	Length													
	Gross Floor Area													
	Height													
	Maintenance Space													
	Net Floor Area													
	Thickness													
	Weight													
	Width													
	Volume													

		ELECTRICAL									BUILDING AUTOMATION			
PROPERTYSET	PROPERTY	Signaling	Sensors and actuators	Telecommunications Outlet	Riser pipes	Tele Body Wires	Cabling of electrical points	Cabling of telephones	Cabling of security systems	Inverters	RAU-centers	Measurement Sensors	Adjustment and other enclosures	Actuators
TECHNICAL	Actual Volume Flow setpoint													
	Colour													
	Colour Code													
	Colour Temperature													
	Control Address			x										
	Control Unit													
	Current													
	Degree of protection (IP)													
	Design Pressure Static													
	Design Pressure Loss													
	Design Sound Level													
	Design Volume Flow													
	Design Volume Flow setpoint													
	Diameter DN													
	K-factor													
	Lamp Power													
	Lamp Type													
	Luminaire Power													
	Luminous flux													
	Material													
	Measured Pressure													
	Measured Pressure Loss													
	Measured Sound Level													
	Measured Volume Flow													
	Number Of Lamps													
	Power													
	Typical Flow Rate													
	Velocity													
	Voltage													
PHYSICAL	Length													
	Gross Floor Area													
	Height													
	Maintenance Space													
	Net Floor Area													
	Thickness													
	Weight													
	Width													
	Volume													

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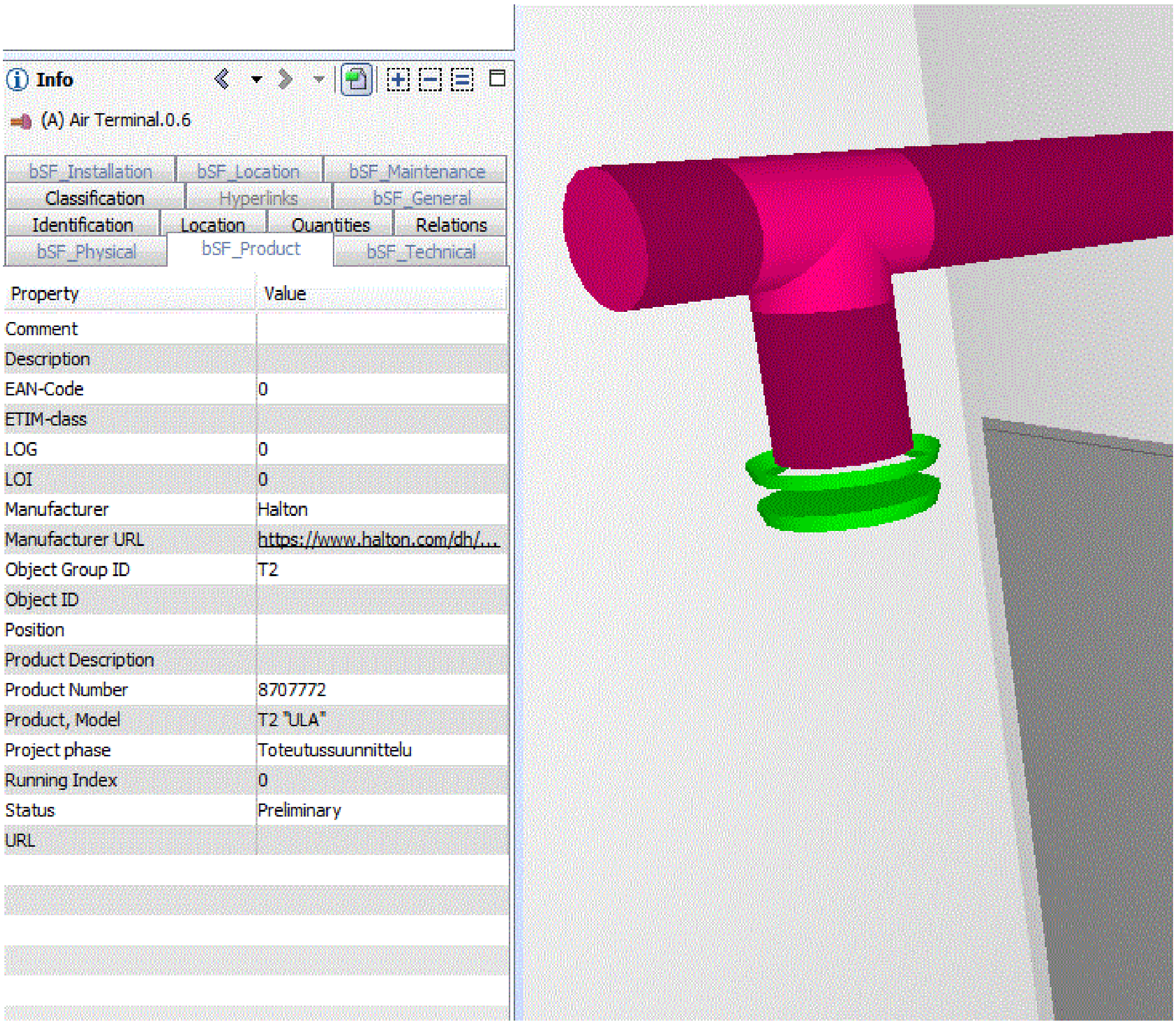
PROPERTYSET	PROPERTY: IFC- File Information	MagiCAD	CADS
ELECTRICAL	Transformers	IfcFlowController / IfcElectricalApplianceType	
ELECTRICAL	Switchgear		
ELECTRICAL	Main switchboards	IfcFlowController	IfcDistributionElement
ELECTRICAL	Busbar-Automatic power products	IfcCableSegmentType / IfcCableCarrierSegmentType /	IFCFLOWSEGMENT, CabelCarrierSegmentType (CONDUITSEGMENT)
ELECTRICAL	Compatible backup chargers	IfcElectricalApplianceType	
ELECTRICAL	The batteries	IfcFlowController / IfcElectricalApplianceType	
ELECTRICAL	Distribution Units	IfcFlowController	IfcDistributionElement
ELECTRICAL	Cross-connection Racks	IfcFlowController	IfcDistributionElement
ELECTRICAL	Central telecommunications	IfcFlowController	IfcDistributionElement
ELECTRICAL	Central control systems for security systems	IfcFlowController	IfcDistributionElement
ELECTRICAL	Cable shelves and hanging rails	IfcCableCarrierSegmentType	IFCFLOWSEGMENT, CabelCarrierSegmentType(CABLELADDERSEGMENT)
ELECTRICAL	Cable management	IfcCableCarrierSegmentType	
ELECTRICAL	Floor channels and boxes	IfcCableCarrierSegmentType / IfcElectricalApplianceType /	IFCFLOWSEGMENT, CabelCarrierSegmentType
ELECTRICAL	Profiles and hangings	IfcCableCarrierSegmentType	IFCFLOWSEGMENT, CabelCarrierSegmentType
ELECTRICAL	Fixtures	IfcLightFixtureType	IFCFLOWTERMINAL, LightFixtureType
ELECTRICAL	Poistumisvalaisimet	IfcLightFixtureType	IFCFLOWTERMINAL, LightFixtureType
ELECTRICAL	Emergency and safety lights	IfcLightFixtureType	IFCFLOWTERMINAL, LightFixtureType
ELECTRICAL	Switches	IfcSwitchingDeviceType	IFCFLOWCONTROLER, SwitchingDeviceType
ELECTRICAL	Sockets	IfcOutletType	IFCFLOWTERMINAL, Outlettype(POWEROUTLET)
ELECTRICAL	Motion and presence sensors	IfcSwitchingDeviceType / IfcAlarmType / IfcSensorType	
ELECTRICAL	Safety switches	IfcSwitchingDeviceType / IfcElectricalApplianceType	IFCFLOWCONTROLER, SwitchingDeviceType
ELECTRICAL	Sharing and junction boxes	IfcJunctionBoxType	IFCFLOWFITTING, JunctionBoxType
ELECTRICAL	Tannoy	IfcElectricalApplianceType	IFCFLOWTERMINAL, Outlettype (AUDIOVISUALOUTLET)
ELECTRICAL	Cameras	IfcAlarmType / IfcElectricalApplianceType	IFCFLOWTERMINAL, Outlettype (AUDIOVISUALOUTLET)
ELECTRICAL	Smoke detector	IfcAlarmType	IFCFLOWTERMINAL, Outlettype (COMMUNICATIONS)
ELECTRICAL	Fire buttons	IfcAlarmType	IFCFLOWTERMINAL, Outlettype (COMMUNICATIONS)
ELECTRICAL	Signaling	IfcAlarmType	IFCFLOWTERMINAL, Outlettype (COMMUNICATIONS)
ELECTRICAL	Sensors and actuators	IfcElectricalApplianceType / IfcAlarmType	IFCFLOWTERMINAL, Outlettype (AUDIOVISUALOUTLET)
ELECTRICAL	Telecommunications Outlet	IfcOutletType	IFCFLOWTERMINAL, Outlettype (AUDIOVISUALOUTLET)
ELECTRICAL	Riser pipes	IfcCableSegmentType	
ELECTRICAL	Tele Body Wires	IfcCableSegmentType	
ELECTRICAL	Cabling of electrical points	IfcCableSegmentType	
ELECTRICAL	Cabling of telephones	IfcCableSegmentType	
ELECTRICAL	Cabling of security systems	IfcCableSegmentType	
ELECTRICAL	Inverters	IfcElectricalApplianceType	
BUILDING AUTOMATION	RAU-centers	IfcFlowController	
BUILDING AUTOMATION	Measurement Sensors	IfcControllerType	
BUILDING AUTOMATION	Adjustment and other enclosures	IfcActuatorType	
BUILDING AUTOMATION	Actuators		

APPENDIX H4: SELECTION LIST

PROPERTY	SELECTION LIST
Object type	Fire damper Variable air volume damper Balancing damper
Discipline	Architectural Building services Electrical Heat Structural Ventilation Plumbing Sprinkler Cooling Special piping Process
Existing installation	Yes No
Install/Supplier	AU IU PU REH RU SPR SU
Status	Preliminary Approved Installed As built Purchased
Project phase	Proposal Planning General Design Implementation Planning Construction Site Phase Maintenance

APPENDIX H5: IFC EXAMPLE

An example of an IFC file using buildingSMART property queues.



21.0 APPENDIX I: COMPANY B

APPENDIX I1: DATA REQUIREMENT

1. Data Requirement

- Maximo Asset
- Visualization Only

2. In PCMB Project?

- YES
- NO

3. Is Product Modeled?

- YES
- NO
- (blank)

4. Which Trade Model?

- PCMB-M_FABRICATION.rvt
- PCMB-MP_FABRICATION.rvt
- (blank)
- HVAC

5. Is Product Tagged Uniq...

- NO
- YES
- (blank)

Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	Attribute Sets	UCSF Tag Abbreviation
23-33 25 00: Air-Handling Units	23-33 25 00	Air-Handling Units	**A_AHU**	AHU
23-33 29 00: HVAC Dampers	23-33 29 23	Fire Smoke Damper Combination	**A_COMMON**	FSD
	23-33 29 37	Volume Control Dampers	**A_COMMON**	VDMPR
23-33 31 00: Air Circulators				
23-33 33 00: HVAC Fan Coil Units	23-33 33 11	Fan Coil Units (Cooling)	**A_COMMON/A_MOTOR/A_HVAC FAN/A_FILTER**	FCU
		Fan Coil Units (Heating)	**A_COMMON/A_MOTOR/A_HVAC FAN/A_FILTER**	FCU
23-33 35 00: HVAC Coils	23-33 35 00	HVAC Coils (Heating)	**A_COMMON**	HC, RHC, CC
23-33 41 17: Terminal Air Units	23-33 41 17 11	Constant Volume Air Terminal Units	**A_COMMON/A_CAV**	CAV
	23-33 41 17 13	Variable Air Volume Terminal Units	**A_COMMON/A_VAV**	VAV

APPENDIX I2: ATTRIBUTE SETS

ATTRIBUTE INFORMATION		REVIT IMPLEMENTATION				COBie IMPLEMENTATION			MAXIMO IMPLEMENTATION			
ATTRIBUTE SET	ATTRIBUTE NAME	REVIT PARAMETER NAME	REVIT PARAMETER TYPE	SHARED PARAMETER NAME	REVIT DATA TYPE	SHEET	FIELD	COBie PARAMETER NAME	TABLE	ATTRIBUTE	MAXIMO DATA TYPE	
A_COMMON	Manufacturer	Manufacturer	Type	*N/A*	Text	Type	Manufacturer	COBie.Type.Manufacturer	ASSET	MANUFACTUREI	AlphaNumeric (35 characters max)	
	Model Number	Model	Type	*N/A*	Text	Type	ModelNumber	COBie.Type.ModelNumber	ASSET	MODELID	AlphaNumeric (50 characters max)	
	Serial Number	Serial Number	Instance	N/A	Text	Component	SerialNumber	COBie.Component.SerialNumber	ASSET	SERIALNUM	AlphaNumeric (50 characters max)	
	Unit Tag [1]	Mark	Instance	UCSF Tag	Text	Component	TagNumber	COBie.Component.TagNumber	ASSET	ALIAS	AlphaNumeric (30 characters max)	
	Description	Description	Type	*N/A*	Text	Type	Description	COBie.Type.Description	ASSET	DESCRIPTION	AlphaNumeric (100 characters max)	
	OmniClass Number [2]	OmniClass Number	Type	*N/A*	Text	Type	Category	COBie.Type.Category	CLASSIFICATIOI	CLASSIFICATIOI	AlphaNumeric (192 characters max)	
	OmniClass Name	OmniClass Title	Type	*N/A*	Text	Type	Category	COBie.Type.Category	CLASSIFICATIOI	DESCRIPTION	AlphaNumeric (100 characters max)	
	Asset ID	*N/A*	Instance	UCSF AssetID	Text	Component	BarCode	COBie.Component.BarCode	ASSET	ASSETNUM	AlphaNumeric (20 characters max)	
	Scope	*N/A*	Type	UCSF BIM4FM	Boolean	*Attribute*	*Name*	*COBie.Attribute.Name*	*N/A*	*N/A*	*N/A*	
	Building Name	Building Name	Project	*N/A*	Text	Facility	Name	COBie.Facility.Name	*N/A*	*N/A*	*N/A*	
	Level	Level	N/A	*N/A*	Number	Floor	Name	COBie.Floor.Name	*N/A*	*N/A*	*N/A*	
	Maximo Location Concatenation [3]	*N/A*	N/A	*N/A*	*N/A*	Space	Name	COBie.Space.Name	ASSET	LOCATION	AlphaNumeric (20 characters max)	
A_BELT	V-Belt size	*N/A*	?	UCSF V-Belt Size	Text	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	VBELT	Alphanumeric	
	V-Belt quantity	*N/A*	?	UCSF V-Belt Qty	Text	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	VBLTQTY	Alphanumeric	
A_CAV	Minimum Airflow	*N/A*		UCSF CAV Minimum Airflow	Number	Attribute	Name					
	Maximum Airflow	*N/A*		UCSF CAV Maximum Airflow	Number	Attribute	Name					
	Reheat Coil Capacity	*N/A*		UCSF CAV Reheat Coil Capacity	Number	Attribute	Name					
	Reheat Coil Waterflow (GPM)	*N/A*		UCSF CAV Reheat Coil Waterflow (GPM)	Number	Attribute	Name					
A_COMPRESSOR	Delivered Air Capacity	N/A		UCSF COMP Delivered Air Capacity	Number	Attribute	Name		ASSETATTRIBUT	COMAIRCAPDEL	Numeric	
	Air Tank National Board Number	N/A		UCSF COMP Air Tank National Board Number	Number	Attribute	Name		ASSETATTRIBUT	ATNBNO	Alphanumeric	
A_MOTOR	Horsepower	*N/A*	Type	UCSF HP	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	
	Frame	*N/A*	Type	UCSF Frame	Text	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	Picklist: NEMA Frame Designa
	RPM	*N/A*	Type	UCSF RPM	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	
	Enclosure Type	*N/A*	Type	UCSF EnclTYpe	Text	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	Picklist:
	Full Load Amps (FLA)	*N/A*	Type	UCSF Amps	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	
	Volts	*N/A*	Type	UCSF Volts	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUT	ASSETATTRID.*x*	Alphanumeric	
	Phase	*N/A*	Type	UCSF Phase	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUTE			Picklist: 1, 3
	Hertz	*N/A*	Type	UCSF Hertz	Number	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUTE			Pattern
	Service Factor	*N/A*	Type	UCSF Service Factor	Text	Attribute	Name	COBie.Attribute.Name	ASSETATTRIBUTE			

APPENDIX I3: BUILDING FABRIC SHELL

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets	Data Requirement [Maximo Asset, Visualization Only]	LOD
B30 EXTERIOR HORIZONTAL ENCLOSURES	23-13 39 00: Roof Coverings, Claddings, Linin	23-13 39 31	Roof Membranes	IRMA, WPM	A_COMMON	Maximo Asset	
B30 EXTERIOR HORIZONTAL ENCLOSURES	23-13 41 00: Roof Specialties and Accessorie	23-13 41 39	Roof Drains	RD, ORD	A_COMMON	Maximo Asset	
B30 EXTERIOR HORIZONTAL ENCLOSURES	23-19 00 00: Specialty Products	23-19 29 19 11	Sound, Vibration and Seismic Control Products		A_COMMON	Maximo Asset	
C10 INTERIOR CONSTRUCTION	23-17 19 11: Hardware for Doors	23-17 19 11 31	Automatic Door Controls and Operators	DR	A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-17 21 00: Protection of Openings	23-17 21 15	Fire and Smoke Shutters and Curtains	SGC	A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-19 00 00: Specialty Products	23-19 11 21	Plaques		A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-21 19 00: Casework	23-21 19 15 15 11	Medical Specialty Casework		A_COMMON	Maximo Asset	

System [Uniformat Level 1 Number: Name]	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
B30 EXTERIOR HORIZONTAL ENCLOSURES	YES	NO	PCMB-ARCH-EXT	NO	Including: flashing, expansion joints, vents, soffits, gutters, bituminous membrane roofing	
B30 EXTERIOR HORIZONTAL ENCLOSURES	YES	NO	PCMB-P_FABRICATION.rvt	NO		
B30 EXTERIOR HORIZONTAL ENCLOSURES	YES	YES		YES		
C10 INTERIOR CONSTRUCTION	YES	NO	PCMB-ARCH-INT	NO		
C10 INTERIOR CONSTRUCTION	YES	YES	PCMB-ARCH-INT	NO		
C10 INTERIOR CONSTRUCTION	YES	NO		NO	Subtype: Dimensional Letter Signage	
C10 INTERIOR CONSTRUCTION	YES	YES	PCMB-EQ	NO		

APPENDIX I4: BUILDING INTERIOR

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets	Data Requirement [Maximo Asset, Visualization Only]	LOD
C10 INTERIOR CONSTRUCTION	23-17 19 11: Hardware for Doors	23-17 19 11 31	**Automatic Door Controls and Operators**	DR	A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-17 21 00: Protection of Openings	23-17 21 15	**Fire and Smoke Shutters and Curtains**	SGC	A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-19 00 00: Specialty Products	23-19 11 21	**Plaques**		A_COMMON	Maximo Asset	400
C10 INTERIOR CONSTRUCTION	23-21 19 00: Casework	23-21 19 15 15 11	**Medical Specialty Casework**		A_COMMON	Maximo Asset	

System [Uniformat Level 1 Number: Name]	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
C10 INTERIOR CONSTRUCTION	YES	NO	PCMB-ARCH-INT	NO		
C10 INTERIOR CONSTRUCTION	YES	YES	PCMB-ARCH-INT	NO		
C10 INTERIOR CONSTRUCTION	YES	NO		NO	Subtype: Dimensional Letter Signage	
C10 INTERIOR CONSTRUCTION	YES	YES	PCMB-EQ	NO		

APPENDIX I5: LIFT AND CONVEYOR INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets	Data Requirement [Maximo Asset, Visualization Only]	LOD
D10 Conveying	23-23 11 00: Vertical Transportation Equipment	23-23 11 11	**Elevators**	ELV	A_COMMON/A_MOTOR/A_ELEVATOR_LIFT	Maximo Asset	500
D10 Conveying	23-23 11 00: Vertical Transportation Equipment	23-23 11 11 21	**Elevator Equipment and Controls**				500
D10 Conveying	23-23 13 00: Lifting Equipment	23-23 13 11	**Lifts**	LFT	A_COMMON/A_ELEVATOR_LIFT	Maximo Asset	300
D10 Conveying	23-23 17 00: Materials Handling	23-23 17 11	**Dumbwaiters**	DWTR	A_COMMON	Maximo Asset	500
D10 Conveying	23-23 17 00: Materials Handling	23-23 17 21	**Pneumatic Tube Systems**	PTS	A_COMMON	Maximo Asset	500
D10 Conveying	23-23 23 00: Loading Dock Equipment	23-23 23 00	**Loading Dock Equipment**			Maximo Asset	500

System [Uniformat Level 1 Number: Name]	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
D10 Conveying	YES	YES	PCMB-ARCH-INT.rvt	YES		
D10 Conveying	YES					
D10 Conveying	NO	YES	PCMB-ARCH-INT.rvt	YES		
D10 Conveying	YES	YES	PCMB-ARCH-INT.rvt	NO		
D10 Conveying	YES	NO	PCMB-P.dwg	NO		
D10 Conveying	NO					

APPENDIX I6: PLUMBING INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Drainage pump**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Potable-water storage tanks**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Sanitary sewage pump**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Steam condensate pump**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Storage tank pump**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 00	**Stormwater drainage pump**	NO					
D20 Plumbing	23-27 17 00: Pumps	23-27 17 31 17	**Vacuum pump**	YES	YES	PCMB-P_FABRICATION.rvt	YES		
D20 Plumbing	23-27 21 00: Compressors	23-27 21 00	**Air Compressors**	NO	YES	PCMB-MP_FABRICATION.rvt	YES		
D20 Plumbing	23-27 23 00: Heat Exchangers	23-27 23 00	**Heat Exchangers (plumbing)**	YES	YES	PCMB-MP_FABRICATION.rvt	YES		
D20 Plumbing	23-27 29 00: Tanks and Storage Structures	23-27 29 19	**Domestic water expansion tank**	YES	YES	PCMB-P_FABRICATION.rvt	YES		
D20 Plumbing	23-27 29 00: Tanks and Storage Structures	23-27 29 19	**Gas system tank**	NO					
D20 Plumbing	23-27 29 00: Tanks and Storage Structures	23-27 29 19	**Gray water tank**	NO					
D20 Plumbing	23-27 29 00: Tanks and Storage Structures	23-27 29 19	**Sanitary tank**	NO	YES				
D20 Plumbing	23-27 31 00: Valves	23-27 31 00	**Valves**	YES	YES	PCMB-P_FABRICATION.rvt/PCMB-MP_FABRICAT	YES		
D20 Plumbing	23-27 33 00: Valve Actuators	23-27 33 00	**Valve Actuators**	NO					
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Compressed-Air for Lab and Healthc**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Compressed-Air Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Domestic Water Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Drainage Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Facility Storm Drainage Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Facility Water Distribution Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Healthcare Chemical-waste and vent**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Healthcare Gas Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Hydronic-piping**	YES	YES	PCMB-MP_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Laboratory Chemical-waste and vent**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Laboratory Gas Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Rainwater Leader Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Sanitary Drain, Waste and Vent Pipin**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Sanitary Utility Sewerage Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Vacuum Piping for Lab and Healthca**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Waste Anesthesia Gas Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Water Utility Distribution Piping**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**De-ionized Water Piping**	YES					
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Distilled Water Piping**	YES					
D20 Plumbing	23-27 39 00: Piping	23-27 39 00	**Carbon Dioxide Fire-Extinguishing P**	NO					
D20 Plumbing	23-27 55 00: Liquid Treatment Components	23-27 55 11	**Liquid Filters**	NO					
D20 Plumbing	23-27 55 00: Liquid Treatment Components	23-27 55 21	**Liquid Deionizers**	NO					
D20 Plumbing	23-27 55 00: Liquid Treatment Components	23-27 55 23	**Liquid Deaerators**	NO					
D20 Plumbing	23-27 55 00: Liquid Treatment Components	23-27 55 29 19	**Reverse Osmosis Units**	NO					
D20 Plumbing	23-27 57 27: Air Filters	23-27 57 27	**Stand-alone filters/banks**	YES	NO	PCMB-M_FABRICATION.rvt	NO		
D20 Plumbing	23-27 57 27: Air Filters	23-27 57 27 15	**ULPA Filters**	NO					
D20 Plumbing	23-27 57 27: Air Filters	23-27 57 27 17	**HEPA Filters (Stand-alone filters/ban**	YES	NO	PCMB-M_FABRICATION.rvt	NO		
D20 Plumbing	23-27 57 27: Air Filters	23-27 57 27 19	**BIBO (Bag-In / Bag-Out) HEPA Air Fil**	YES	YES	PCMB-M_FABRICATION.rvt	YES		
D20 Plumbing	23-27 57 00: Gas Treatment Components	23-27 57 31	**Electronic Air Cleaners**	NO					
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 13 00	**Sinks**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 15 00	**Bathtubs**	NO					
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 17 00	**Showers**	YES					
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 19 00	**Toilets**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 21 00	**Urinals**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 23 00	**Bidets**	NO	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 29 00	**Hot Water Heaters**	NO					
D20 Plumbing	23-31 00 00: Plumbing Specific Products and Equipment	23-31 31 00	**Drinking Fountains**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-29 37 00: Occupational Safety and Health Equipment	23-29 37 13	**Emergency Eye Wash Stations**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-29 37 00: Occupational Safety and Health Equipment	23-29 37 15	**Emergency Showers**	YES	YES	PCMB-ARCH-INT.rvt	NO		
D20 Plumbing	23-39 29 00: Waste Water Collection and Removal	23-39 29 11	**Sanitary Drains**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-39 29 00: Waste Water Collection and Removal	23-39 29 11 13	**Waste Water Storm Drain**	YES	YES	PCMB-P_FABRICATION.rvt	NO		
D20 Plumbing	23-39 29 00: Waste Water Collection and Removal		**Sanitary Waste Interceptors**	NO					
D20 Plumbing	23-39 29 00: Waste Water Collection and Removal		**Sanitary Waste Separators**	NO					

APPENDIX I7: HVAC INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets
D30 HVAC	23-27 17 00: Pumps	23-27 17 00	Fuel-oil pump	CP	
D30 HVAC	23-27 17 00: Pumps	23-27 17 00	Boiler feedwater pump		
D30 HVAC	23-27 17 00: Pumps	23-27 17 13	Hydronic pump	CP	A_COMMON/A_MOTOR/A_PUMP
D30 HVAC	23-27 23 00: Heat Exchangers	23-27 23 00	Heat Exchangers (hvac)	HEX	A_COMMON/A_HEAT EXCHANGER
D30 HVAC	23-33 11 00: Commercial Boilers	23-33 11 00	Commercial Boilers	BLR	
D30 HVAC	23-33 11 00: Commercial Boilers	23-33 11 13	Condensing Boilers	BLR	
D30 HVAC	23-33 11 00: Commercial Boilers	23-33 11 17	Flexible Tube Boilers	BLR	
D30 HVAC	23-33 11 00: Commercial Boilers	23-33 11 21	Water Tube Boilers	BLR	
D30 HVAC	23-33 11 00: Commercial Boilers	23-33 11 22	Electric Boilers	BLR	
D30 HVAC	23-33 15 00: HVAC Heating Units	23-33 15 21	Hydronic HVAC Heaters	HHWC	
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 11	Central Package Unit Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 11	Centrifugal Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 13	Reciprocating Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 17	Rotary Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 19	Rotary Screw Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 21	Screw Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 21 00: Chillers	23-33 21 13 23	Scroll Chillers	CH	A_COMMON/A_MOTOR/A_CHILLER
D30 HVAC	23-33 23 00: Cooling Towers	23-33 23 11	Mechanical Draft Cooling Towers	CT	A_COMMON/A_MOTOR/A_COOLING-TOWER
D30 HVAC	23-33 23 00: Cooling Towers	23-33 23 13	Natural Draft Cooling Towers	CT	
D30 HVAC	23-33 25 00: Air-Handling Units	23-33 25 00	Air-Handling Units	AHU	A_AHU
D30 HVAC	23-33 27 00: Air Humidity Control Equipment	23-33 27 13	Dehumidifiers	DHUMD	A_COMMON
D30 HVAC	23-33 27 00: Air Humidity Control Equipment	23-33 27 15	Air Humidifiers	HUM	A_COMMON/A_HUMIDIFIER
D30 HVAC	23-33 29 00: HVAC Dampers	23-33 29 19	Dampers	DMPR	A_COMMON
D30 HVAC	23-33 29 00: HVAC Dampers	23-33 29 23	Fire Dampers	FDMPR	A_COMMON
D30 HVAC	23-33 29 00: HVAC Dampers	23-33 29 23	Fire Smoke Damper Combination	FSD	A_COMMON
D30 HVAC	23-33 29 00: HVAC Dampers	23-33 29 25	Smoke Dampers	SDMPR	A_COMMON
D30 HVAC	23-33 29 00: HVAC Dampers	23-33 29 37	Volume Control Dampers	VDMPR	A_COMMON
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 19	Booster Fan	BFN	A_COMMON/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 19	Exhaust Fan	EFN	A_COMMON/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 19	Fans	FN	A_COMMON/A_MOTOR/A_FAN
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 19	Return Fan	RFN	A_COMMON/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 19	Supply Fan	SFN	A_COMMON/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 21	Power Ventilators (Cooling)	VENT	A_COMMON/A_MOTOR/A_HVAC POWER VENTILATORS
D30 HVAC	23-33 31 00: Air Circulators	23-33 31 21	Power Ventilators (Heating)	VENT	A_COMMON/A_MOTOR/A_HVAC POWER VENTILATORS
D30 HVAC	23-33 33 00: HVAC Fan Coil Units	23-33 33 11	Fan Coil Units (Cooling)	FCU	A_COMMON/A_MOTOR/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 33 00: HVAC Fan Coil Units	23-33 33 11	Fan Coil Units (Heating)	FCU	A_COMMON/A_MOTOR/A_HVAC FAN/A_FILTER
D30 HVAC	23-33 35 00: HVAC Coils	23-33 35 00	HVAC Coils (Cooling)	HC	A_COMMON
D30 HVAC	23-33 35 00: HVAC Coils	23-33 35 00	HVAC Coils (Heating)	HC, RHC, CC	A_COMMON
D30 HVAC	23-33 37 00: Refrigerant Condensing Units	23-33 37 00	Refrigerant Condensing Units		
D30 HVAC	23-33 39 00: Air Conditioning Equipment	23-33 39 11	Air Conditioners	AC	A_COMMON
D30 HVAC	23-33 39 00: Air Conditioning Equipment	23-33 39 15	Make Up Air Units	AC	
D30 HVAC	23-33 39 00: Air Conditioning Equipment	23-33 39 17	Packaged Air Conditioners	AC	
D30 HVAC	23-33 39 00: Air Conditioning Equipment	23-33 39 19	Packaged Terminal Air Conditioning Units	PTAC	
D30 HVAC	23-33 39 00: Air Conditioning Equipment	23-33 39 21	Split System Air Conditioning Units	AC	
D30 HVAC	23-33 41 17: Terminal Air Units	23-33 41 17 11	Constant Volume Air Terminal Units	CAV	A_COMMON/A_CAV
D30 HVAC	23-33 41 17: Terminal Air Units	23-33 41 17 13	Variable Air Volume Terminal Units	VAV	A_COMMON/A_VAV
D30 HVAC	23-33 43 00: HVAC Condenser Units	23-33 43 11	Air Cooled Condenser Units	ACCU	
D30 HVAC	23-33 43 00: HVAC Condenser Units	23-33 43 13	Evaporative Condenser Units		
D30 HVAC	23-33 43 00: HVAC Condenser Units	23-33 43 15	Refrigeration Condenser Units		
D30 HVAC	23-33 43 00: HVAC Condenser Units	23-33 43 17	Water Cooled Condenser Units		
D30 HVAC	23-33 49 00: HVAC Ductwork	23-33 49 11	Ventilation Diffusers	REG	A_COMMON
D30 HVAC	23-33 49 00: HVAC Ductwork	23-33 49 15	Duct Access Panels	DAP	A_COMMON
D30 HVAC	23-33 49 00: HVAC Ductwork	23-33 49 23	Grilles	REG	A_COMMON
D30 HVAC	23-33 49 00: HVAC Ductwork	23-33 49 25	Ventilation Registers	REG	A_COMMON
D30 HVAC	23-33 51 00: HVAC Specialized Equipment	23-33 51 15	Ultraviolet Disinfection Lighting (Cooling)	UV	A_COMMON/A_LIGHT-FIXTURE
D30 HVAC	23-33 51 00: HVAC Specialized Equipment	23-33 51 15	Ultraviolet Disinfection Lighting (Heating)	UNS	A_COMMON/A_LIGHT-FIXTURE

System [Uniformat Level 1 Number: Name]	Data Requirement [Maximo Asset, Visualization Only]	LOD	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-MP_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		YES	YES	PCMB-MP_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO				Subtype: Cast-iron Radiator, Finned Tube Radiators, Plate Radiators	
D30 HVAC	Maximo Asset		YES	YES	PCMB-MP_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-MP_FABRICATION.rvt	YES		Not in project
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO	YES	PCMB-M_FABRICATION.rvt	YES		Not in project
D30 HVAC	Maximo Asset		YES	YES	PCMB-MP_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		YES	YES				
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	NO		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO	NO	PCMB-M_FABRICATION.rvt	NO	Resolved w/ AHU attributes	All fans are covered elsewhere
D30 HVAC	Maximo Asset		NO	YES	PCMB-M_FABRICATION.rvt	YES		Not in project
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		Not in project
D30 HVAC	Maximo Asset		YES	YES			Subtype: Gravity Ventilator	
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		Not in project
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO	YES	PCMB-M_FABRICATION.rvt	NO		Not in project
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	NO	Resolved w/ AHU attributes	Not in project
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		YES	YES	PCMB-M_FABRICATION.rvt	YES		
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Maximo Asset		NO					
D30 HVAC	Visualization Only		YES	YES	PCMB-M_FABRICATION.rvt	NO		
D30 HVAC	Visualization Only		YES	YES	PCMB-M_FABRICATION.rvt	NO		
D30 HVAC	Visualization Only		YES	YES	PCMB-M_FABRICATION.rvt	NO		
D30 HVAC	Visualization Only		YES	YES	PCMB-M_FABRICATION.rvt	NO		
D30 HVAC	Maximo Asset		YES	NO	PCMB-M_FABRICATION.rvt	NO	Resolved w/ AHU attributes	AHU
D30 HVAC	Maximo Asset		NO	NO	PCMB-M_FABRICATION.rvt	NO		Not in project

APPENDIX I8: FIRE PROTECTION INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets	Data Requirement [Maximo Asset, Visualization Only]	LOD
D40 Fire Protection	23-27 17 00: Pumps	23-27 17 00	**Fire pump**	FP	A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 23 00: Fireproofing Components	23-29 23 17	**Smoke Seals for Ductwork**	DUCT	A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 25 00: Fire Fighting Equipment	23-29 25 15 19	**Fire Hose Connectors**		A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 25 00: Fire Fighting Equipment	23-29 25 19	**Fire Extinguishers**	FE	A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 29 00: Fire Detection Devices	23-29 29 11	**Fire Alarm Pull Stations**		A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 29 00: Fire Detection Devices	23-29 29 13	**Fire Detectors**		A_COMMON	Maximo Asset	
D40 Fire Protection	23-29 33 00: Fire Suppression System Components	23-29 33 11	**Water Based Suppression Equipment**		A_COMMON	Visualization Only	
D40 Fire Protection	23-29 33 00: Fire Suppression System Components	23-29 33 13 13	**Carbon Dioxide Suppression Equipment**		A_COMMON	Maximo Asset	
D40 Fire Protection	23-39 35 00: Water and Wastewater Chemical Feed Equipment	23-39 35 11 17	**Fuel-Gas Detection and Alarm**		A_COMMON	Maximo Asset	

System [Uniformat Level 1 Number: Name]	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
D40 Fire Protection	NO					
D40 Fire Protection	YES	NO	PCMB-M_FABRICATION.rvt	NO	MOVE TO HVAC	
D40 Fire Protection	YES	NO	PCMB-FP.dwg	NO		
D40 Fire Protection	YES	YES	PCMB-ARCH-INT.rvt	NO		
D40 Fire Protection	YES	YES	PCMB-E.rvt	NO		
D40 Fire Protection	YES	YES	PCMB-E.rvt	NO		
D40 Fire Protection	YES	NO	PCMB-FP.dwg	YES	Include: valves, piping, sprinkler heads	
D40 Fire Protection	NO	NO	PCMB-FP.dwg	NO		
D40 Fire Protection	NO					

APPENDIX I9: ELECTRICAL INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	Attribute Sets
D50 Electrical	23-35 13 00: Transformers	23-35 13 00	Medium Voltage Transformers	XFMR	A_COMMON/ A_TRANSFORMER / A_ELEC
D50 Electrical	23-35 13 00: Transformers	23-35 13 01	Low Voltage Transformers		A_COMMON/ A_TRANSFORMER / A_ELEC
D50 Electrical	23-35 23 00: Power Conditioning Equipment	23-35 23 21	Uninterrupted Power Supply (UPS) Units	UPS	A_COMMON / A_ELEC
D50 Electrical	23-35 25 00: Electrical Instrumentation and Controls	23-35 25 00	Electrical Instrumentation and Controls (Cooling)		A_COMMON
D50 Electrical	23-35 25 00: Electrical Instrumentation and Controls	23-35 25 00	Electrical Instrumentation and Controls (Heating)		A_COMMON
D50 Electrical	23-35 31 00: Electrical Power Distribution Devices	23-35 31 17	Electrical Cabinets and Enclosures		A_COMMON
D50 Electrical	23-35 31 00: Electrical Power Distribution Devices	23-35 31 17	Electrical Panel Boards	ESP	A_COMMON / A_ELEC
D50 Electrical	23-35 31 00: Electrical Power Distribution Devices	23-35 31 29	Substations	SS	A_COMMON / A_ELEC
D50 Electrical	23-35 31 00: Electrical Power Distribution Devices	23-35 31 29	Switchboards	SWBD	A_COMMON / A_ELEC
D50 Electrical	23-35 33 00: Electrical Ducting Wireways Components	23-35 33 17	Electrical Conduits		A_COMMON
D50 Electrical	23-35 33 00: Electrical Ducting Wireways Components	23-35 33 19	Electrical Cable Trays		A_COMMON
D50 Electrical	23-35 33 00: Electrical Ducting Wireways Components	23-35 33 21	Electrical Bus Ducts		A_COMMON
D50 Electrical	23-35 33 00: Electrical Ducting Wireways Components	23-35 33 25	Electrical Wireways		A_COMMON
D50 Electrical	23-35 37 00: Electrical Switches	23-35 37 11	Automatic Transfer Switches	ATS	A_COMMON / A_ELEC
D50 Electrical	23-35 47 11: Lighting Fixtures	23-35 47 11	Interior Light Fixtures		A_COMMON/A_LIGHT-FIXTURE / A_ELEC
D50 Electrical	23-35 47 13: Emergency Lighting	23-35 47 13 13	Emergency Lighting With Battery Backup	EML	A_COMMON / A_ELEC
D50 Electrical	23-35 47 15: Exit Illuminated Signs	23-35 47 15 13	Hard Wired Backup Exit Illuminated Signs	ES	A_COMMON / A_ELEC

System [Uniformat Level 1 Number: Name]	Data Requirement [Maximo Asset, Visualization Only]	LOD	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES		CEI
D50 Electrical	Maximo Asset		YES	YES				
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	NO		
D50 Electrical	Visualization Only		YES	NO	HVAC	NO		
D50 Electrical	Visualization Only		YES	NO	HVAC	NO		Don't think this is tagged
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES		
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES	AKA: Distribution Panel Boards	
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES	Substations	
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES		CEI
D50 Electrical	Visualization Only		YES	YES	PCMB-E.rvt	NO		
D50 Electrical	Visualization Only		YES	YES	E, LV	NO		
D50 Electrical	Visualization Only		YES	YES	PCMB-E.rvt	NO		
D50 Electrical	Visualization Only		YES	YES	PCMB-E.rvt	NO		
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	YES		
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	NO	Subtype: Task Lighting, Interior Lighting Fixtures	
D50 Electrical	Maximo Asset		YES	YES	PCMB-E.rvt	NO		
D50 Electrical	Maximo Asset		YES	YES	PCMB-ARCH-INT.rvt	YES		

APPENDIX I10: EQUIPMENT INSTALLATION

System [Uniformat Level 1 Number: Name]	Product Class [OmniClass Level 2 Number: Name]	OmniClass [OmniClass Level 3/4 Number]	Product [OmniClass Level 3/4 Name]	UCSF Tag Abbreviation	PCMB Tag	Attribute Sets
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment	23-25 47 11 13 11	Powered Treatment Exam Tables		TBL	A_COMMON
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment	23-25 45 11 11 17	Patient Bed Service Walls		Multiple	A_COMMON
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment	23-25 63 13 35	Radiation Detection Or Monitoring Products		MRD	A_COMMON
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment	23-25 63 13 15 23	MRI Utility Tables		TBU	A_COMMON
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment	23-25 63 13 17	Ultrasound Imaging Tables		TIM	A_COMMON
E10 Equipment	23-25 00 00: Medical and Laboratory Equipment		Bariatric Exam / Treatment Tables		TBL	A_COMMON
E10 Equipment	23-37 27 00: Emergency Communications	23-37 27 17 13	Nurse Call Equipment		NCS	A_COMMON

System [Uniformat Level 1 Number: Name]	Data Requirement [Maximo Asset, Visualization Only]	LOD	In PCMB Project? [Yes/No]	Modeled?	Trade Model	Tagged individually in Model?	UCSF Additional Notes	Trade Comments
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-EQ.rvt	YES		
E10 Equipment	Maximo Asset		YES	YES	PCMB-LV.rvt	NO		

22.0 APPENDIX J: COMPANY C

APPENDIX J1: BUILDING COMPONENT SUMMARY

DTU

DTU Building Component Summary

Version.
Ver. date:

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This excel sheet is a project's building sectional overview with accompanying information and references to documents. For instructions for completion please download:

DTU IKT-2.53 Advisor's Guide in Delivery of DV-Documentation.

DTU IKT-2.54 Entrepreneur's guide in submitting DV documentation.

The link guide is available

http://www.dtu.dk/Om-DTU/Praktisk-information/For-leverandoerer/DTU_Standarder/Standarder_BIM_IKT

PROJECT SPECIFIC INFORMATION

DTU case number:	
DTU Surname:	
DTU project manager:	
Entrepreneur:	
Due date:	
Building Number:	
site:	

APPENDIX J2: STRUCTURE SUMMARY SHEET

DTU Structure summary SHEET

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General, primary building parts

IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL [Pulling directly from the model]															
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheet	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, charts, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model Type	Warranty start date	Comments	Location	Number/Quantity	Color (RAL / NCS)	Surface	Material	D-value	Active or passive fire system [Select from drop down in cell]	Fire classification (REI) [Select from drop down in cell]	Static system? [Select from drop down in cell]	Inside or outside [Select from drop down in cell]	Movable? [Select from drop down in cell]	Floor Type [Select from drop down in cell]	Balcony Type [Select from drop down in cell]	Ceiling Type [Select from drop down in cell]	Ceiling (removable?) [Select from drop down in cell]	Note on accessibility
(2.)							General, primary building parts																															
	(2=)						Primary building parts, building and terrain, sum																															
	(20)						Primary building parts, terrain																															
		(20)4		AD			Techniques in terrain, incl. tube bridges and tunnels																															
	(23)						Deck, primary building parts																															
		(23)2		AC			Floor slabs																															
		(23)4		ULE			Beams																															
	(27)						Roof, primary building parts																															
		(27)1		AE			Roofing																															
		(27)2		RQD			Canopies and covers // Porches //																															
	(28)						Primary building parts, building, others																															
	(29)						Primary building parts, building, sum																															
		(29)1		ULD			Columns																															
		(29)2.01		NAC			Grid																															
		(29)3		XSC			Fixed ladders																															
(3.)							General, complementary building parts																															
	(3=)						Complementary BD building and terrain, sum																															
	(31); (32)						Walls, completion																															
		(31)1		AD			Walls																															
		(31)2; (32)1		QQC			Doors																															
		(31)3		QQE			Ports																															
		(31)4		QQA			Windows																															
		(32)2		QQD			Hatches, Shutters																															
	(33)						Deck, Completion																															
		(33)1		NCC			Floors																															
	(34)						Stairs and ramps, completion																															
		(34)4		AF			Stairs																															
		(34)5		AG			Ramps																															
	(35)						Ceilings, completion																															
		(35)1		NCD			Ceilings																															
	(36)						Balconies, completion																															
		(36)2		NCC			Balconies																															
		(36)3		NCC			Balcony Hallways																															
	(37)						Roof, completion																															
		(37)2.01		QQA			Skylights																															
		(37)2.02		QQD			Smoke hatches																															

DTU

Structure summary SHEET

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General, primary building parts

IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS		
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type number link to model	System number	Building part name or System name
	(38)						Complementary BD building, others
	(39)						Complementary BD building, sum
(7.)							General, inventory
	(7=)						Fittings and equipment building and terrain, sum
	(72)						Boards, signs and screens
		(72)1		PHD			Signs
		(72)3		RB			AV equipment, boards, projector screens
	(73)						Storage furniture (fixed fixtures)
		(73)1		RB			Shelf (fixed)
		(73)2		RB			Cabinets and drawer furniture (fixed)
		(73)3		RB			Kitchen cabinet (fixed)
		(73)4		RB			Laboratory equipment (fixed)
	(77)						Fittings, Furnishings and shielding textiles
		(77)1		RQE			Blinds and curtains
		(77)2		PLF			Carpets and mats
		(77)3		RQF			Blinds
	(78)						Other furniture
	(79)						Fixtures and equipment building, sum
(8.)							Other facilities
	(81)						Fire hydrants
	(89)						Other facilities, sum

	DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]						
Building part name or System name	KS-materials	Datasheets	Warranty Sheet	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, charts, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model Type	Warranty start date	Comments
Complementary BD building, others															
Complementary BD building, sum															
General, inventory															
Fittings and equipment building and terrain, sum															
Boards, signs and screens															
Signs															
AV equipment, boards, projector screens															
Storage furniture (fixed fixtures)															
Shelf (fixed)															
Cabinets and drawer furniture (fixed)															
Kitchen cabinet (fixed)															
Laboratory equipment (fixed)															
Fittings, Furnishings and shielding textiles															
Blinds and curtains															
Carpets and mats															
Blinds															
Other furniture															
Fixtures and equipment building, sum															
Other facilities															
Fire hydrants															
Other facilities, sum															

	BIM-MODEL [Pulling directly from the model]															
Building part name or System name	Location	Number/Quantity	Color (RAL / NCS)	Surface	Material	D-value	Active or passive fire system [Select from drop down in cell]	Fire classification (REI) [Select from drop down in cell]	Static system? [Select from drop down in cell]	Inside or outside [Select from drop down in cell]	Movable? [Select from drop down in cell]	Floor Type [Select from drop down in cell]	Balcony Type [Select from drop down in cell]	Ceiling Type [Select from drop down in cell]	Ceiling (removable?) [Select from drop down in cell]	Note on accessibility
Complementary BD building, others																
Complementary BD building, sum																
General, inventory																
Fittings and equipment building and terrain, sum																
Boards, signs and screens																
Signs																
AV equipment, boards, projector screens																
Storage furniture (fixed fixtures)																
Shelf (fixed)																
Cabinets and drawer furniture (fixed)																
Kitchen cabinet (fixed)																
Laboratory equipment (fixed)																
Fittings, Furnishings and shielding textiles																
Blinds and curtains																
Carpets and mats																
Blinds																
Other furniture																
Fixtures and equipment building, sum																
Other facilities																
Fire hydrants																
Other facilities, sum																

APPENDIX J3: BUILDING PARTS OVERVIEW BMS (AUTOMATIC)

DTU Building Parts Overview BMS (Automatic)

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL	
SfB Code Level 1	SfB Code Level 2	SfB Code Level 3	Subcategory	CCS	Type Number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Warranty start date	Comments	Location	Number/Quantity
(5.)							**General, plumbing system**																	
	(5=)						**Plumbing system , building and terrain, sum**																	
	(50)						**Plumbing system, terrain**																	
		(50)1		JD			Drainage Construction																	
		(50)2		JD			sewage system																	
		(50)6		QC			Liquid storage system																	
		(50)7		KF			Pump System																	
		(50)8		KD			Separation System																	
	(52)						**Drains and sanitation**																	
		(52)1		JD			Drainage System																	
		(52)5		JD			Consumption System																	
		(52)6		KF			Pump System																	
	(53)						**Water (cold, hot, treated water)**																	
		(53)1		HB			Water supply system																	
		(53)2		JB			Water Distribution system																	
		(53)3		KE			Water treatment plant																	
	(54)						**Gases (gas, compressed air, vacuum, steam)**																	
		(54)1		HA			Gas and air supply systems																	
		(54)2		JA			Gas and air distribution systems																	
		(54)3		JA			consumption Systems																	
		(54)6		QB			Gas and air storage systems																	
	(55)						**Cooling**																	
		(55)1		HC			Heat supply systems																	
		(55)2		JF			Cooling distribution systems																	
		(55)3		JF			Consumption Systems																	
	(56)						**Heat (water, steam, condensation, thermal fluid)**																	
		(56)1		HD			District Heating Systems																	
		(56)2		JG			Heat Distribution Systems																	
		(56)3		JG			Consumption Systems																	
	(57)						**Ventilation**																	
		(57)1		HF			Ventilation systems																	
		(57)2		JJ			Air Distribution systems																	
		(57)3		JJ			Consumption Systems																	
	(58)						**Plumbing plant, building, others**																	
		(58)1		PB			Sprinkler systems																	
		(58)2		KE			Water Purification Plant																	
		(58)3					Special systems for liquids																	

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Building Parts Overview BMS (Automatic)

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL	
SfB Code Level 1	SfB Code Level 2	SfB Code Level 3	Subcategory	CCS	Type Number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Warranty start date	Comments	Location	Number/Quantity
(6.)							**General, electrical and mechanical systems**																	
	(6=)						**Electrical and mechanical systems building and terrain, sum**																	
	(60)						**Terrain, electrical and mechanical systems**																	
		(60)2		HH			Road and space lighting systems																	
		(60)3					Installation for underground systems																	
		(60)4					Installation for on systems																	
	(62)						**High-voltage switchgear**																	
		(62)1		HG			Supply																	
		(62)2		JK			Main distribution																	
		(62)5		JK			Electrical engineering systems																	
	(63)						**Low-voltage switchgear**																	
		(63)1		HG			Supply																	
		(63)2		JK			Main distribution																	
		(63)5		HH			Lighting systems																	
	(64)						**Electronics and low voltage systems**																	
		(64)4		JL			IT infrastructure																	
			(64)4.01	XGC			X-fields																	
			(64)4.02	XGC			BMS-concentration point																	
			(64)4.03	WGB			Cabling																	
		(64)5		LC			Process Control Systems																	
		(64)6					Management Systems																	
			(64)5.01	KA			Solar screening																	
			(64)5.02	KB			Window Automation																	
		(64)7					Central mode control																	
			(64)7.01	LC			CTS- Systems																	
			(64)7.02	LC			IBI- Systems with central management																	
		(64)8					Decentralized state control																	
			(64)8.01	LC			IBI systems with distributed management																	
	(65)						**Fuse**																	
		(65)1					Building materials																	
			(65)1.01	LE			Automatic burglar alarm system (AIA system)																	
			(65)1.02	LD			Access Control Systems (ADK Systems)																	
			(65)1.03	LF			Internal CCTV equipment (CCTV) systems																	
		(65)2					Fire protection																	
			(65)2.01	LB			Automatic fire alarm system (ABA system)																	
			(65)2.02	PA			Automatic fire extinguisher system (ABDL plant)																	
			(65)2.03	LA			Automatic gas alarm system (AGA)																	
			(65)2.04	PB			Automatic room extinguishing system (ARS system)																	
			(65)2.05	PB			Automatic for sprinkler systems (ACS plants)																	
			(65)2.06	HF			Automatic Fire Ventilation System (ABV)																	
		(65)3					Personal Security																	
			(65)3.01	MA			Alarm systems																	

APPENDIX J4: BUILDING PARTS OVERVIEW ELECTRICAL INSTALLATIONS

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]										BIM-MODEL		[Pulling directly from the model]
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type Number link to model	Systems number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Serial Number	EAN-13	Board Number	Warranty Start Date	Comments	Location	Number	Active or passive fire system [Select from drop down in cell]
(6.)							**General, electrical and mechanical systems**																					
	(6=)						**Electrical and mechanical system building and terrain, sum**																					
	(60)						**Terrain, electrical and mechanical installations**																					
		(60)1					Plugs outside the building																					
			(60)1.01	WBB			Air lines for high voltage systems																					
			(60)1.02	WBB			Wires in ground for high voltage systems																					
			(60)1.03	WDB			Air conduits for low voltage systems																					
			(60)1.04	WDB			Wires in ground for low voltage systems																					
			(60)1.05	WDB			Wires for electronics and low power systems																					
		(60)2		HH			Road and space lighting systems																					
			(60)2.01	HH			Street and road lighting systems																					
			(60)2.02	HH			Area Lighting																					
			(60)2.03	HH			Park and garden lighting systems																					
		(60)3					Installation for underground systems																					
			(60)3.01	PC			Ground electrode plant																					
			(60)3.02				Oil separator systems																					
			(60)3.03	KF			Pump system in well																					
			(60)3.04				Registration system for grease separator																					
			(60)3.05	JG			Heating cable systems																					
			(60)3.06				Leak detection system																					
			(60)3.07				Frost detection system																					
		(60)4					Installation for on ground systems																					
			(60)4.01	UBD			Mast																					
		(60)5		MC			Traffic management																					
	(61)						**Guideways**																					
		(61)1					High voltage cable paths																					
			(61)1.01	UBA			Pipes																					
			(61)1.02	UBA			Cable Trays																					
			(61)1.03	UBA			Cable Ladders																					
			(61)1.04	UBA			Cable Grave																					
		(61)2					Low voltage cables																					
			(61)2.01	UBA			Pathways in prefabricated building sections																					
			(61)2.02	UBA			Pipes																					
			(61)2.03	UBA			Cable Trays																					
			(61)2.04	UBA			Cable Ladders																					
			(61)2.05	UBA			Cable Channels																					
			(61)2.06	UBA			Installation Channels																					
			(61)2.07	UBA			Cable Grave																					
			(61)2.08	UBA			Cable Tray																					
		(61)3		UBA			Cableways for machine systems																					
		(61)4					Holes and recessesr																					
		(61)4.01		XTA			Holes																					
		(61)4.02		XTB			Cutouts																					
		(61)5		NAE			Fire and sound seals																					
	(62)						**High-voltage switchgear System**																					
		(62)1		HG			Supply																					
			(62)1.01	WBB			Service pipes																					
			(62)1.02	TAA			Transformer																					
		(62)2		JK			Main distribution																					
			(62)2.01	WBB			Main pipes																					
			(62)2.02	FCA			Switchgear																					
			(62)2.03	UAA			Panels																					
		(62)3					Installations for appliances and machines																					
		(62)4		JK			Secondary high voltage systems																					
		(62)5		JK			Electrical engineering system																					

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]										BIM-MODEL		
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type Number link to model	Systems number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Serial Number	EAN-13	Board Number	Warranty Start Date	Comments	Location	Number	Active or passive fire system [Select from drop down in cell]
(63)							**Low voltage systems**																					
	(63)1			HG			Supply																					
		(63)1.01		WDB			Service pipes																					
		(63)1.02		TAA			Transformer																					
		(63)1.03		UAA			Transformer Panels																					
		(63)1.04		RBA			Emergency and Reserve Supply (UPS)																					
	(63)2			JK			Main distribution																					
		(63)2.01		WDB			Main pipes																					
		(63)2.02		UAA			Main Distribution Boards																					
		(63)2.03		UAA			Group Distribution Boards																					
		(63)2.04		UAA			Switchboards																					
		(63)2.05		UAA			Light boards																					
		(63)2.06		UAA			Special boards																					
		(63)2.07		UAA			Other boards																					
	(63)3						Machinery and machine systems																					
		(63)3.01		TAE			Inverter																					
	(63)4						Thermal systems																					
		(63)4.01		EPE			Electric radiator																					
		(63)4.02		EPA			The electrical heating element																					
		(63)4.03		EBE			Hand dryer, heated towel rail																					
		(63)4.04		EMA			Oven system																					
		(63)4.05					Radiation Heating																					
		(63)4.06					Heating Cable Systems																					
	(63)5			HH			Lighting systems																					
		(63)5.01		HH			Systems for general lighting																					
		(63)5.02		HH			System for Low Voltage Lighting																					
		(63)5.03		HH			Emergency lighting system																					
		(63)5.04		HH			Special lighting facility																					
		(63)5.05		HH			Light dimming Systems																					
		(63)5.06		XDB			Construction sockets																					
		(63)5.07		WDB			Supply of computer installations																					
		(63)5.08					Installations in laboratories and test sites																					
		(63)5.09		JP			Trunking Systems																					
	(63)6						All lighting fixtures																					
		(63)6.01		UAC			Lighting fixture																					
(64)							**Electronics and low voltage systems**																					
	(64)1						Communication																					
	(64)2						Information																					
	(64)3						Audio, video and antenna																					
	(64)4						IT infrastructure																					
		(64)4.01		XGC			X-fields																					
		(64)4.02		XGC			BMS-concentration distribution point																					
		(64)4.03		WDB			Cabling																					
	(64)5			LC			Process Control Systems																					
		(64)5.01		KA			Solar screening																					
		(64)5.02		KB			Window Automation																					
	(64)7						Central mode control																					
		(64)7.01		LC			CTS-System																					
		(64)7.02		LC			IBI- system with central control																					
	(64)8						Decentralized state control																					
		(64)8.01		LC			IBI-system with distributed management																					
(65)							**Fuse**																					
	(65)1						Building materials																					
		(65)1.01		LE			Automatic burglar alarm system (AIA system)																					
		(65)1.02		LD			Access Control Systems (ADK Systems)																					
		(65)1.03		LF			Internal CCTV equipment (TVO) systems																					
	(65)2						Fire protection																					
		(65)2.01		LB			Automatic fire alarm system (ABA)																					
		(65)2.02		PA			Automatic fire extinguishing system (ABDL)																					
		(65)2.04		PB			Automatic room closure system (ARS)																					
	(65)3						Personal security system																					
		(65)3.01		MA			Alarm system																					
(66)							**Conveyor systems**																					
	(66)1			CND			Elevators																					
	(66)2			AF			Escalators																					
(67)							**Mechanical installations, others**																					
(68)							**Electrical installation building, others**																					
(69)							**Electrical and mechanical plant building, sum**																					

APPENDIX J5: BUILDING PARTS OVERVIEW LANDSCAPE

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]									BIM-MODEL [Pulling directly from the model]					
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type Number link to model	Systems number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Guarantee start date	Coating type [select from drop down cell]	Plant type [select from drop down cell]	Comments	Location	Number	Color (RAL / NCS)	Surface	Material	Note on accessibility
(2.)							**General, primary building parts**																							
	(2=)						**Primary building parts, building and terrain, sum**																							
	(20)						**Primary building parts, terrain**																							
		(20)2		AD			Fencing walls																							
		(20)3		AD			Retaining walls																							
(3.)							**General, complementary building parts**																							
	(3=)						**Complementary BD building and terrain, sum**																							
	(30)						**Complementary building parts, terrain**																							
		(30)2		RUA			Fence																							
		(30)3					Stairs, ramps in terrain																							
		(30)3.01		AG			Ramps																							
		(30)3.02		AF			Stairs																							
(4.)							**General, surface building parts**																							
	(4=)						**Surfaces, building and terrain, sum**																							
	(40)						**Terrain, coatings**																							
		(40)1		AB			Surfaces, secondary buildings																							
			(40)1.02	RUA			Waste Farms / Islands																							
			(40)1.03	RUA			Gas farms																							
			(40)1.06	RUA			Espalier																							
		(40)2		AA			Trails, coatings																							
		(40)3		AA			Roads, p-areas, coatings																							
		(40)4		AA			Living areas, coatings																							
		(40)5		AA			Sports and garden areas, coatings																							
		(40)7		AA			Plants for planting																							
			(40)7.01	BYA			Grass																							
			(40)7.02	BYA			Flowers																							
			(40)7.03	BYA			Bushes																							
			(40)7.04	BYA			Hedges																							
			(40)7.05	BYA			Trees																							

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]									BIM-MODEL [Pulling directly from the model]					
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type Number link to model	Systems number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model type	Guarantee start date	Coating type [select from drop down cell]	Plant type [select from drop down cell]	Comments	Location	Number	Color (RAL / NCS)	Surface	Material	Note on accessibility
(5.)							**General, plumbing plant**																							
	(5=)						**Plumbing plant, building and terrain, sum**																							
	(53)						**Water (cold, hot, treated water)**																							
		(53)4					Water, terrain																							
			(53)4.01				Pools, living																							
			(53)4.02				Mirror pools																							
			(53)4.03				Overflow pools																							
			(53)4.04				Fountain																							
(7.)							**General, inventory**																							
	(7=)						**Fittings and equipment building and terrain, sum**																							
	(70)						**Inventory, terrain**																							
		(70)1					Technical inventory devices, P-machines, etc.v																							
			(70)1.01	RUB			Barriers																							
			(70)1.02	QQE			Shutters																							
			(70)1.03	JB			Irrigation systems																							
			(70)1.04				Charging posts and stations																							
			(70)1.05	GPA			Pump																							
		(70)2		PHD			Boards, signs and screens																							
		(70)3					Storage, waste racks, bicycle racks, mailboxes, etc.																							
			(70)3.01				Ashtray																							
		(70)4		GG			Table Furniture																							
		(70)5					Seating Area																							
		(70)6					Training Equipment																							
	(78)						**Other furniture**																							
		(78)3					Indoor planting																							
			(78)3.01	RA			Hanging gardens																							
			(78)3.02	RA			Rooftop gardens																							
			(78)3.03	RA			Green roof																							
			(78)3.04	RA			Green facades, inside																							
			(78)3.05	RA			Indoor Planting																							
			(78)3.06	RA			Green facades, exterior																							

APPENDIX J6: BUILDING PARTS OVERVIEW TERRAIN

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL		[Pulling directly from the model]
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model Type	Warranty start date	Comments	Location	Number	Active or passive fire system [Select from drop down in cell]
(5.)							**General, plumbing system**																		
	(5=)						**Plumbing system, building and terrain, sum**																		
	(50)						**Plumbing system, terrain**																		
		(50)1		JD			Drainage Systems																		
		(50)2		JD			Sewage system																		
		(50)6		QC			Liquid storage system																		
		(50)7		KF			Pump Systems																		
		(50)8		KD			Separator Systems																		

APPENDIX J7: BUILDING PARTS OVERVIEW VENTILATION

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL		(Pulling directly from the model)
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model Type	Warranty start date	Comments	Location	Number	Active or passive fire system [Select from drop down in cell]
(5.)							**General, plumbing system**																		
	(5=)						**Plumbing system, building and terrain, sum**																		
	(57)						**Ventilation**																		
		(57)1		HF			Ventilation systems																		
		(57)2		JJ			Air Distribution systems																		
		(57)3		HF			Consumption Systems																		
(6.)							**General, electrical and mechanical systems**																		
	(6=)						**Electrical and mechanical system building and terrain, sum**																		
	(65)						**Fuse**																		
		(65)2					Fire protection																		
			(65)2.03	LA			Automatic gas alarm system (AGA)																		
			(65)2.06	HF			Automatic Fire Ventilation System (ABV)																		

APPENDIX J8: BUILDING PARTS OVERVIEW PLUMBING INSTALLATIONS

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IDENTIFICATION					REFERENCES TO MODEL AND DRAWINGS			DOCUMENTATION TYPE								GENERAL INFORMATION [numerical or text value]							BIM-MODEL [Pulling directly from the model]		
SfB code level 1	SfB code level 2	SfB code level 3	Subcategory	CCS	Type number link to model	System number	Building part name or System name	KS-materials	Datasheets	Warranty Sheets	Configuration	Descriptions (operating descriptions, function descriptions etc.)	Drawings (as well as charts, diagrams, etc.)	Instructions	Other things	Life expectancy	Installation Date	Supplier	Producer	Model Type	Warranty start date	Comments	Location	Number	Active or passive fire system [Select from drop down in cell]
(5.)							**General, plumbing system**																		
	(5=)						**Plumbing plant, building and terrain, sum**																		
	(52)						**Drains and sanitation**																		
	(53)						**Water**																		
	(54)						**Gasses**																		
	(55)						**Cooling**																		
	(56)						**Heat**																		
	(58)						**Plumbing plant, building, others**																		
		(58)3					Special systems for liquids																		
(6.)							**General, electrical and mechanical systems**																		
	(6=)						**Electrical and mechanical system building and terrain, sum**																		
	(65)						**Fuse**																		
		(65)2					Fire protection																		
			(65)2.04	PB			Automatic room extinguishing system (ARS system)																		
			(65)2.05	PB			Automatic for sprinkler systems (ACS plants)																		

APPENDIX J9: SELECTION LIST

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Selection List

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FREQUENCY	INTERVAL	TASK TYPE	ACTIVE OR PASSABLE FIRE SYSTEM	REPLY	LOFT TYPE	BRAND CLASS (REI)	GALLERY TYPE	ORIENTATION	FLOOR TYPE	PLANTING TYPE	COATING TYPE
1 time per	month	Legal requirement	Active	Yes	suspended	MATERIALS	Cantilevered	Inside	Floating	GRASS	Asphalt
2 times per	2 months	Guarantee	Passive	No	Surface mounted	A2-s1, d0	Detached	Outer	Modular	Sports Lawn	Concrete
3 times per	3 months	Comfort	Not applicable	Not applicable	Not applicable	B-s1, d0	Hitched	Not applicable		Use Lawn	Natural stone
4 times per	4 months	Legal requirements and warranty	Do not know	Do not know	Do not know	D-s2, d2	Freestanding	Do not know		grass Flat	Gravel
5 times per	6 months	Not applicable				CLOTHING	Not applicable			Common Grass	Other things
6 times per	9 months	Do not know				K1 10 B-s1, d0	Do not know			natural Grass	
	12 months					K1 10 D-s2, d2				FLOWERS	
	18 months					FLOORING				Rose Prayer	
	24 months					A2fl-s1				perennial beds	
	36 months					DFL-s1				summer Flowers	
	48 months					ROOFING				climbers	
	60 months					BROOF (t2)				BUSHES	
	120 months					PROPERTY BUILDINGS, NOT DISCUSSING				ornamental shrubs	
						R 30 A2-s1, d0				Bottom-shrugging bushes	
						R 60 A2-s1, d0				bushy	
						R 120 A2-s1, d0				thickets	
						R 30				HEDGE	
						R 60				Hedge	
						PROPERTY AND ADDITIONAL BUILDINGS				Cut pur	
						REI 30 A2-s1, d0				TREES	
						REI 60 A2-s1, d0				Free-growing trees	
						REI 60-M A2-s1, d0				All	
						REI 120 A2-s1, d0				Shaped trees	
						REI 120-M A2-s1, d0				Forest	
						REI 30				Grove	
						REI 60					
						NON-PROHIBITED AND ADDITIONAL BUILDINGS					
						EI 30 A2-s1, d0					
						EI 60 A2-s1, d0					
						EI 60-M A2-s1, d0					
						EI 120 A2-s1, d0					
						EI 120-M A2-s1, d0					
						EI 30					
						EI 60					
						E 30					
						E 60					
						DOORS					
						EI2 60-C A2-s1, d0					
						EI2 30-C					
						EI2 30					
						EI2 60-C					
						E 30-C					
						Not applicable					
						Do not know					