A study of the concept of future-proofing in healthcare building asset management and the role of BIM in its delivery

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By

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Abstract

This research assessed the concept of future-proofing (FP) as a proactive initiative for enterprise asset management is an urgent need against uncertainty, particularly in health care due to unforeseeable demographic shifts and rapid advances in medical technology. Building information modelling (BIM) is a data-driven initiative but a rigorous analysis will indicate that a synergy exists.

A multiphase design methodology was adopted to cover as much breadth and depth around the synergies that exist between future-proofing and BIM both in terms of delivery (supply chain) and in an enterprise context (organisational structures). In the first phase, an exploratory survey was conducted. The exploratory data were gathered to include responses of industry experts. The findings provide valuable insights regarding the integration of flexibility and design standardisation and whether this integration can improve change-readiness in designing future-proof healthcare facilities.

Then, a first round of primary and secondary case study data were gathered from a major public asset owner organisation. The findings focused on the governance of BIM and FP in an enterprise context. As such three agendas emerged, namely government, strategic management and, due to the opportunities that BIM brings, information management. Then, a second round of primary qualitative data were collected and a series of interviews were conducted. The interviews targeted the opinion of leading industry experts across all phases of a project. At this phase the aim was to develop a classification ontology of the interactions between FP and BIM during project delivery.

Finally, the findings were triangulated. As such, a reference model was developed, concentrating on the functional and organisational aspects of the core business of a service organisation. Finally, the three types of findings were connected to give a deployment plan for future-proofing asset management taking into account adoption of innovation which service providers can use to manage their assets across an enterprise.

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Contents

Figures

Tables

Abbreviations and Acronyms

ADB	Activity Database
AEC	Architecture, Engineering and Construction industry
AIM	Asset Information Model
AIR	Asset Information Requirements
AM	Asset Management
AR	Action Research
BEP	BIM Execution Plan
BIM	Building Information Modelling
BREAM	Building Research Establishment Environmental Assessment Methodology
BS	British Standards
CAD	Computer Aided Design
CAPEX	Capital expenditure
COBie	Construction Operations Building Information Exchange
CPO	Current preferred option
DH	Department of Health
EIR	Employer Information Requirements
FM	Facilities Management
FP	Future-proofing
GSL	Government Soft Landings
GT	Grounded Theory
HBN	Health Building Notes
HTM	Health Technical Memoranda
IFC	Industry Foundation Classes
IPA	Interpretative Phenomenological Analysis
IPD	Integrated Project Delivery
IT	Information Technology
LIFT	Local Improvement Finance Trust
LOS	Length of stay
MEP	Mechanical Electrical and Plumbing
MPDT	Model Production Delivery Table
NBS	National British Standards
NHS	National Health System
NRM	New Methods of Measurement
OPEX	Operational expenditure
P21	Procure21, NHS procurement framework
PAS	Public Available Specification
PFI	Private Finance Initiative
PIM	Project Information Model
RIBA	Royal Institute of British Architects
ROI	Return on Investment
SP	Scenario Planning
SPO	Single preferred option

TA	Thematic Analysis
UK	United Kingdom
WCC	World Class Commissioning

Chapter 1 Introduction

This thesis presents the interfaces of two concepts, namely future-proofing (FP) and Building Information Modelling (BIM) in an enterprise context. In particular this study explores the interfaces between FP in enterprise asset management and a metacritique of BIM in terms of managing FP. The combination of these two concepts could bring confusion when their impact and effectiveness are assessed in an enterprise. In literature the two concepts (FP and BIM) are presented as two independent unrelated initiatives, although they both seem to focus on change.

1.1 *Background*

Health care and its executive teams face a policy environment characterized by change on several fronts (e.g. reforms in health services, government initiatives for improving working conditions of staff, etc.). With change, there is uncertainty and thus has an impact on the ongoing delivery of service strategies, organizational culture, and the way the Trusts (divisions within the UK's National Health Service, NHS) operate locally. According to Capper et al. (2012), the main issue is the reluctance of the NHS system to enforce strategies that will address sustainability related planning conditions.

Health care assets exist in a complex operational and technological environment and thus identifying the requirements information (both as procurers and as supply chain) from a whole-life information management perspective is crucial for ensuring design life. Additionally, global austerity measures are causing reduction of investments in all sectors, and the construction sector is no exception. However, owners are seeking other ways to overcome the financial crisis by investing in the application of sustainability; and for a building to achieve sustainability, the designers recognize that it has to be also future-proofed (Krygiel & Nies, 2008).

While the traditional idea was to procure and deliver health care facilities as 'complete' projects, in other words, projects with fixed requirements; it has transpired that hospitals are very complex dynamic facilities and cannot be built as programmatically static (Kendall 2005; de Neufville et al. 2008). In this context, Francis (2010) stressed the question *"how can we ensure that what we are building* *now will be fit for the future*?" and then proposed that a dynamic system approach is necessary to deal with change.

Masood et al. (2013) suggested that *"information could also play an important role in supporting whole-life decision-making"*. In support of the above and following the USA and the Scandinavian countries as previous successful examples, the UK has set forth a Building Information Modelling (BIM) initiative which emerged from the 2011 construction strategy (Cabinet Office, 2011) and suggests that construction savings can be achieved if the construction industry manages better the *information* it produces. One of the key challenges from a planning point of view is whether information will be fit for purpose in the long term.

At the outset, a definition of the two concepts, BIM and FP, needs to be drawn. The UK Department of Health (DH, 2013) recognized 13 issues that need to be addressed at each project stage of a health care project regarding excellence in sustainability; one of them being FP. Masood et al. (2013) defined FP as *"the process of incorporating future developments while changing from an unplanned and uncontrolled state to a planned and controlled state of a resilient infrastructure asset or product service system with minimal negative consequence"'*. For the Department of Health (2013), FP is a response where *"buildings should respond to future changes in requirements, change of use, strategic perspectives, clinical/medical drivers, national policy and changing climate".* In an information context, Information futureproofing in infrastructure can be defined as *"the process to ensure that required information is retrievable (reusable) throughout the whole lifecycle of infrastructure assets or product service systems when needed. The key characteristics of information futureproofing may include representability, retrievability, reusability and accessibility"* (Masood et al., 2013). In the remainder of this study, FP is proposed as the dynamic system approach that can address change, whilst BIM is the vehicle that allows FP to be realised in an enterprise context.

1.2 *Research Scope*

The research scope of this study is to formulate the theory of a top-down holistic approach for a deployment plan of enterprise asset management and the use of

BIM. There have been many definitions of BIM and all of them describe a change in process in terms of construction management (British Standards Institute, 2007; Eastman et al., 2011; Shade et al., 2011; Ashworth, 2012; British Standards Institute, 2013, 2014; Demian and Walters, 2014). For the purposes of this research, BIM in this study can be defined as:

BIM (as a verb) is the process of generating and managing component data within an integrated database and parametric model throughout the project's design-build-operate life cycle. The result is a building information model and can be defined as:

A *building information model* (as a noun) is a digital representation of all physical and functional characteristics of a facility or site serving as a shared knowledge resource for information about the assets. This knowledge database forms a reliable basis for information exchange and decisions during a project's life cycle from inception onwards.

Significant changes are expected to occur in the procurement of healthcare facilities due to the introduction of BIM processes and technology as outlined in the Government Construction Strategy (Cabinet Office, 2011). A need in identifying whether the requisite of BIM introduction is driving an owner operator to re-engineer its asset management processes or just to increase performance appears to be significant. The study approaches FP as a holistic phenomenon taking place in the BIM Build environment. In this study, FP is discussed as a key issue in the pursuit of sustainable assets and therefore it can be defined as strategic planning that responds to future changes in requirements, change of use, organisational strategic perspectives, national policy and changing climate and aims to limit the risks inherent in long-term decision-making by providing resilient solutions against future uncertainties.

In order to address the concept holistically, its implementation at project level was assessed. As such, a delivery approach has been developed capturing the project whole-life. A work breakdown structure (WBS) has been developed and is further aligned to BIM capabilities (Chapter 8).

In addition, FP was assessed from an enterprise point of view. As part of the wider organisation agenda, a strategy is presented for managing FP at an enterprise level (Chapter 7). The strategy and implementation plan are then embedded in a wider deployment plan (Chapter 9) which showcases FP and BIM at enterprise level.

In terms of research areas which this research can be positioned, the Venn diagram (Figure 1-1) positions this study in perspective to other research areas. As shown in the graph, the application industry sector of this research is Healthcare, thus a thorough understanding of the organisational policies and how they change as well as healthcare trends that exist deemed necessary to uncover the research need. Taking into consideration the above, the focus of this research was then to propose new ways for owner operators to assess and deploy FP and BIM across the enterprise and its assets.

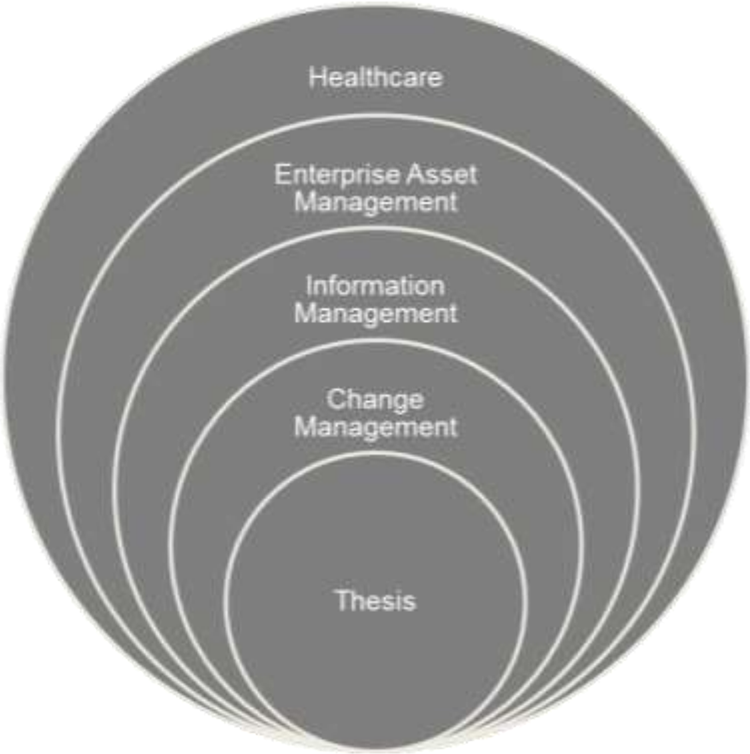


Figure 1-1: Research scope

Information Management principles have been explored and were further aligned to an organisation's strategy[1] (Chapter 7) and also reflecting on project delivery work breakdown structures (Chapter 8). Finally, elements of change management

[1] *Please see Section 7.3.3 Information Management agenda*

research were explored to help shape the final findings of this study and showcase how an organisation adopts and measures the concept of FP across the business and embedding innovative solutions (Chapter 9).

1.3 *Research gaps found in literature*

The literature review and findings from the conducted research strategies identified major gaps and issues regarding deploying future-proofing in enterprise asset management and further exploitation of the benefits found in Information management. The following gaps are summarised below. An extensive literature review is outlined in Chapter 2 to Chapter 4.

1. Lack of positioning flexibility and standardisation in relation to future-proofing.
2. Lack of identifying future-proofing considerations on wide industry based scope, including identifying actionable agendas and leadership competencies at enterprise level leading to future-proofing across all of its enterprise assets.
3. Inability to develop and implement future-proofing at project delivery.
4. Lack of offering a BIM metacritique with regards to its effects on delivery and management at an enterprise level.

1.4 *Research Questions*

The research questions of this study emerged after reviewing the literature and identifying the research gaps outlined in Section 1.2. The following research questions emerged.

Research question 1: How can the supply chain (consultants and contractors) deliver future-proof solutions and how can healthcare organisations manage future-proof healthcare assets at enterprise level?

This research question has two parts. The first part focuses on how the supply chain approaches FP as a phenomenon and strategy to deliver future-proof solutions. The second part focuses in developing the management tools and processes that would allow owner operators to effectively manage their assets at enterprise level.

Research question 2: What is the role of BIM in trying to answer how can the supply chain (consultants and contractors) deliver future-proof projects *and* how can healthcare organisations manage future-proof healthcare assets at enterprise level?

The following questions will help finding answer to the second research question: Does BIM have the capabilities to support a planning approach that prepares the asset against future changes in requirements? Which characteristics of BIM assist more and which could potentially hinder FP flows in an enterprise context? What are the synergies of FP and BIM? What are the benefits of working towards these two concepts?

1.5 *Aim and Objectives*

The aim of this research is to improve and support the delivery (supply chain aspect) *and* management (procurer aspect) process of future-proof healthcare facilities acknowledging the role of BIM.

In order to accomplish the aim, the research methodology was designed to capture the perceptions of both procurers and supply chain partners. Considering the identified research gaps in Section **Error! Reference source not found.** and in order to accomplish the above aim the following five objectives have been formulated.

Objective 1: To identify flexibility and standardisation and their relation to future-proofing.

Objective 2: To develop a governance process for future-proofing in an owner operator enterprise context.

Objective 3: To develop a series of FP objectives and tasks across project delivery.

Objective 4: To identify BIM capabilities and interactions in a future-proofing delivery context.

Objective 5: To develop a future-proofing deployment plan for adoption of future-proofing and innovation in an owner operator enterprise context.

1.6 *Outline Methodology*

This research has been conducted primarily using an inductive approach where strategies are employed with a theory building focus that is driven towards generalisations (Yin, 2008). Qualitative methods were used. This research comprised five objectives which have been mapped against methods and outcomes in Table 1-1. The study addresses the research questions through a multiphase design methodology (Creswell & Clark, 2011) as outline in Chapter 5 and the findings of this methodology are outlined in Chapter 6 to Chapter 9.

Table 1-1: Overview of research objectives, methods and outcomes

Objective	Methods	Journal	PhD Thesis	Chapter
1: To identify flexibility and standardisation and their relation to future-proofing.	Online Survey	Appendix C	X	6
2: To develop a governance process for future-proofing in an owner operator enterprise context.	Case study	Appendix D	X	7
3. To develop a series of FP objectives and tasks across project delivery.	IPA	Appendix E	X	8
4: To identify BIM capabilities and interactions in a future-proofing delivery context.	IPA	Appendix E	X	8
5: To develop a future-proofing deployment plan for adoption of future-proofing and innovation in an owner operator enterprise context.	Triangulation		X	9

1.7 *List of publications*

A number of peer reviewed papers were published to disseminate the insights gained through this research study as summarised in Table 1-2. The papers are appended in the Appendices section.

Table 1-2: List of publications

Paper No.	Paper title	Bibliographical reference	Appendix	Status
Paper 1	Design of flexible and adaptable Healthcare buildings of the future – a BIM approach	Krystallis, I Demian, P and Price, ADF, 2012, Design of flexible and adaptable Healthcare buildings of the future – a BIM approach, *first UK academic conference on bim: conference Proceedings,* Newcastle, 222-232	Appendix A	Published
Paper 2	Supporting future-proof healthcare design by narrowing the design space of Solutions using building information Modelling	Krystallis, I Demian, P and Price, ADF (2013) Supporting future-proof healthcare design by narrowing the design space of solutions using building information modelling In: Smith, S.D and Ahiaga-Dagbui, D.D (Eds) *Procs 29th Annual ARCOM Conference*, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 3-12.	Appendix B	Published
Paper 3	Using Building Information Modelling (BIM) to design flexible spaces with design standards in healthcare facilities	Ahmad, MA Krystallis, I Demian, P and Price, ADF (2014), Using Building Information Modelling (BIM) to design flexible spaces with design standards in healthcare facilities, *J. Civil Eng. Architect. Res.*, 1(5), 312-326.	Appendix C	Published
Paper 4	Future-proofing and BIM for Owner Operators in the UK	Krystallis, I., Vernikos, V., El-Jouzi, S. and Burchill, P., 2016. Future-proofing governance and BIM for owner operators in the UK. *Infrastructure Asset Management*, 3(1), pp.12-20.	Appendix D	Published
Paper 5	Using BIM to integrate and achieve holistic future-proofing objectives in healthcare projects	Krystallis, I., Demian, P. and Price, A.D.F., 2015. Using BIM to integrate and achieve holistic future-proofing objectives in healthcare projects. *Construction Management and Economics*, 33(11-12), pp.890-906.	Appendix E	Published

1.8 *Chapter Summary*

In this chapter, an introduction of this three year study is given briefly outlining the two topics under study, FP and BIM. The background and scope of the study has been covered, followed by the two main research questions this study seeks to address. The research gaps have been outlined as emerged from literature followed by the aim and objectives of this study. In addition, a brief overview of the adopted methodology is given and is further aligned to the objectives and outcomes of this study. Finally, the list of publications is presented.

Chapter 2 Uncertainty in Healthcare

2.1 *Introduction*

In this first literature review chapter, drivers of uncertainty are identified and thus the push-pull interaction between public health trends and the NHS response is covered. Demographic trends such as fertility, mortality, migration and ageing population are discussed by observation of past data. Further discussion continues in reviewing different patterns of disease and care and how epidemics such as heart disease force medical technology to new innovations. In addition, advances in medical technology and clinical knowledge are discussed.

The second aspect focuses on government policy and specifically into how the NHS is changing its healthcare services in order to deal with the above trends. Further discussion covers issues such as distribution of layers and optimal size, forecasting and factors that lead to uncertainty. The discussion proceeds around how forecasters and health managers are making predictions regarding future demand and identifying possible future scenarios.

2.2 *Background*

In 1990s the Private Finance Initiative (PFI) building programme was introduced. Moreover, the internal market softened and GP fund holders were replaced by Primary Care Groups (Gorsky, 2008). At the start of the new millennium, the Department of Health (DH) (DH, 2010) announced reforms in health services, and government initiatives to improve the working conditions of the staff, with better payments, reducing waiting times for patients and improvements in hospitals and surgeries. Services were undergoing significant changes. Lessons from the past provided the NHS evidence that doctors, nurses and staff were fewer than required. In order to deal with the problem, investments in facilities and workforce were made. Literature records this decision as the biggest investment in the history of NHS. Additionally, a ten year vision was proposed to a more patient centred policy. The new investments that came from political agreements and the PFI scheme, promoted local autonomy, through foundation trust status for hospitals and introducing Patient and Public Involvement (PPI) bodies (Gorsky, 2008).

More recently the 2010 white paper '*Liberating the NHS'* (DH, 2010) defined the new role for the NHS. A more detailed review of the paper is described in Section 2.4 of this chapter. In short, the NHS is willing to re-evaluate the role of the general practitioners (GPs) in the whole system. Until recently, acute hospitals in comparison to GPs were an expensive and dominant health care institution. This scheme is undergoing change under the new policy, and the NHS pushes more responsibility to GPs, while acute care facilities are moving to a more specialised direction. Also, other specialties such as psychiatry, geriatrics and rehabilitation care are becoming community based.

2.3 *Public Health Trends*

The following paragraphs outline the public health trends found in World reports and with comments from academic literature.

2.3.1 Demographic Trends

There are three factors that determine the composition of a population and therefore they affect directly the healthcare system:

a) fertility;

b) mortality; and

c) migration.

Trends in future population size and age structure in a big part depend on future levels of fertility, mortality and migration. Each factor implicates changes in the healthcare system and therefore has a direct impact on how the hospital performs (McKee & Healy, 2002). In less than 100 years (1900-1991) the UK population increased by 51% (Hicks & Allen, 1999). It is also noted that the UK population is growing older (Hicks and Allen 1999; Shaw 2001; Gomes & Higginson 2008). During 1901 the proportion of the population over 50 was just 15%; in 1951 it increased to 25% and 31% by 1991 (Shaw, 2001).

Recent reports suggest that the UK is about to become the biggest country in Europe by the end of this century (Figure 2-1). In addition, as the population increases, there are differences in terms of how the population is shaped.

The reports suggest that the 'working age' population will grow at a slower pace compared to the number of dependants (Figure 2-2). One of the results would be that the retirement rate is likely to increase. Such changes in population increase and changes in lifestyle have a significant effect in treatment and the way the NHS operates.

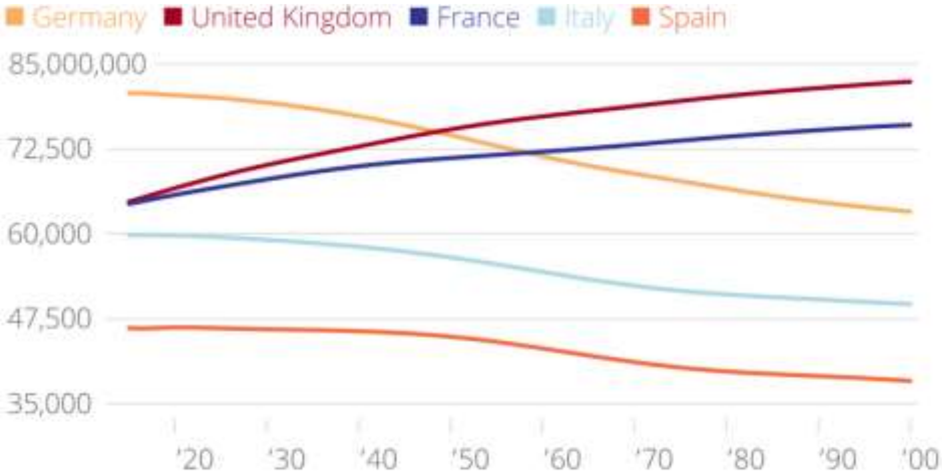


Figure 2-1: Western's Europe's population forecast (City A.M. Limited, 2015)

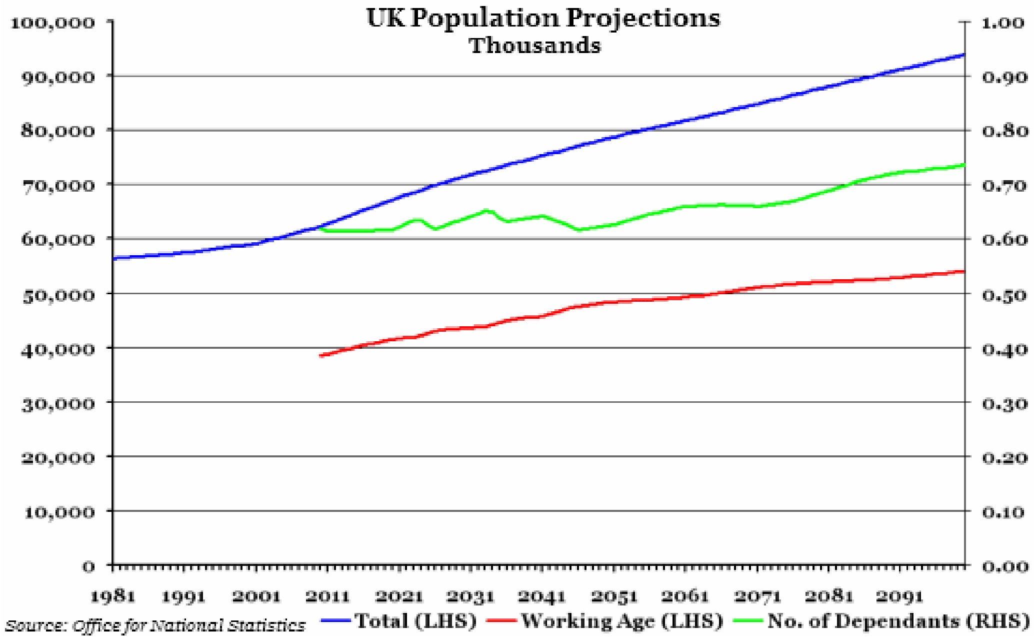


Figure 2-2: UK population projections in thousands (Economic Research Council, 2011)

2.3.2 Changing patterns of disease

The role of the hospital is to host treatment for patients whether they are injured or suffer from a disease. As many empirical results and research have revealed, the general factors that are affecting causes of deaths is determined by a variety of factors such as environmental measures (wealth, education, safety regulation), lifestyle measures (alcohol, tobacco) and healthcare treatment (medical and pharmaceutical) (Shaw et al., 2005). Future epidemics are unlikely to require same treatment as their predecessors, since medical treatment is advancing and struggling to take over control. Though, epidemics such as heart disease, stroke, and other chronic diseases (for example pneumonia) are responsible for the biggest share among deaths and disability in our era (WHO, 2014).

There are often some periods that infectious diseases were not the main interest of health authorities. Cohen (2000) reviewed how infection diseases changed over time and found that during the 80s pharmaceutical companies reduced the development of new antibiotics and that had as a result the born of a new series of epidemics such as the Legionnaire's disease, Ebola virus, HIV, 'flesh-eating' bacteria and 'mad cow disease'. Health organisations have managed though to reduce deaths occurred from infectious diseases (Oller et al., 2009).

2.3.3 Technological advances and patterns of care

The US Office of Technology Assessment (1976) defined medical technologies as *"all the drugs, devices and medical and surgical procedures and the organizational and support systems used to provide them".* Advances in medical technology and clinical knowledge have changed the scheme of healthcare over the last decade. Selected services that provided previously only by hospitals, now offered in community clinics, mobile health units and in patient's home (McKee & Healy, 2002).

Patients often require less time to recover due to new medicines and/or surgical approaches. Tan et al. (1996) stated that advances in surgical process to hospitalised diabetic patients reduced the length of hospital stay by at least six days. Battleman et al. (2002) tested 700 cases related to pneumonia and the results showed that with the appropriate antibiotics, the length of stay in hospitals was significantly reduced. On the other hand, there have been cases, where insurance plans, surgical and pharmaceutical treatments increased hospitalization of patients (Puig-Junoy et al. 2015; Fick, et al. 2013; Chandra et al. 2010). . Furthermore, it was observed that drug consumption also increases population's life expectancy (Brooks, 2014).

Each of these developments has important implications in services, medical practice, equipment and the configuration of the facility (McKee & Healy, 2002). Different patterns of care, especially for the elderly and people with disabilities or mental disorders can highly influence the number of healthcare facilities and to which direction the NHS is willing to spend its resources.

With special medicines patients with serious mental problems such as psychoses can behave normal and be part of the community (McKee & Healy, 2002). Both Freeman (1995) and McKee and Healy (2002) argued that mental healthcare facilities were left unchallenged for too long. Those facilities became obsolete, and although the NHS tried to use them for other health care purposes, those attempts failed because such large institutions were difficult to be transformed for different use.

2.4 *NHS response to socio-technical trends*

Discussions of current approaches of defining trends were presented in the previous sections. The following sections scrutinise how the NHS is dealing with this on-going process and what actions takes to confront them.

2.4.1 **Background and advances in Healthcare policy**

Significant capital investment for Healthcare has taken place in the UK from the start of the new Millennium (DH, 2000.). Programmes such as the NHS Plan in 2000, the Local Improvement Finance Trust (LIFT), the *'2020 Vision'* (Worthington, 2002) and later in 2007 the *'Rebuilding the NHS: A New generation of Healthcare Facilities'* (DH, 2007) demonstrated that the DH is willing to take its role on societies ever-changing needs.

In 2000, the DH introduced the LIFT initiative as part of the NHS Plan. LIFT, as PFI, is a way of accessing private money for public projects (Ibrahim et al., 2009). One of the meeting goals of LIFT initiative is the transition of some of the services from the secondary care to the primary care. In order that goal to be achieved, *"facilities should be flexible and easy to adapt to meet the requirements of the evolving service needs"* (Ibrahim et al., 2009). The DH is trying to provide better and more effective delivery services by building new facilities as well as renovating many others.

The Building Futures '*2020 Vision'* (Worthington, 2002) is a research project established in 2002 by the Royal Institute of British Architects (RIBA) Future Studies Group, Citizens Advice Bureau (CAB), the Nuffield Trust and the Medical Architecture Research Unit (MARU) and their aim was to create a discussion about the society's changing demands, technological and economic trends of the built environment and how these could influence the built environment over the next 20 years. The research focused in identifying trends in social, economic and technological advances that will affect the design of healthcare environments over the next 20 years. As highlighted by the Building Futures research for the UK this was the largest public sector building programme since the 1960s. It was noted that by 2004, the UK Government has spent £18.4bn. Through the Private Finance Initiative (PFI) and associated new forms of contract, the NHS increased its capital budget more and more over the years. One of the key questions that appeared was whether this big investment would meet the demand for high quality healthcare environments for the next 20 years.

Doubts have been expressed whether the new healthcare buildings being built today are able to adapt to the changing needs of the society in the future (Worthington, 2002). Furthermore, the study reported that the healthcare facilities being built now would not adapt well to the future. The study focus was to put the working teams in the centre of the design procedure. The study suggested that health and social care centres should have a synthesis of dedicated and shared spaces, but lacked to investigate how this can be applicable. The NHS along with PFI procured over 70 new hospitals by 2002. These new buildings are in a 30 year PFI contract. The '*2020 vision*' though highlighted that *"many of these buildings could be largely obsolete before the end of this period*". The research highlighted that the majority of the design provision is not following the NHS needs.

In 2010, the DH (2010) published the white paper '*Liberating the NHS'* and the main aim for the next years is to put patients in the centre. By 2010 the DH scheduled to build 100 new Hospitals, 500 new one-stop primary care centres, more than 3000

GPs primary care centres and many other investments. In short the aims of the white paper were:

- putting patients and public first;
- improve healthcare outcomes;
- increase autonomy, accountability and democratic legitimacy; and
- cutting bureaucracy and improving efficiency

Summarising the goals, the *'Liberating the NHS'* was that patients would have the control of what they think it is best for them. The paper received criticisms by many specialists. Fitzpatrick (2010) argued that '*Liberating the NHS'* is a paper with no superficial investigation, and lacks the focus to deliver. Furthermore, the questions that emerged from the report are neither realistic nor applicable. According to Walshe (2010) the structural reorganisation that the DH suggested would not be successful. Walshe stated that *"there is often little evidence to show that the causes of poor performance are structural or that the proposed structural changes will improve performance"*.

With the replacement of stakeholders in decision making, the NHS internal market is changing as well. This means that whereas 152 primary care trusts who were responsible for purchasing secondary care for a defined geographically population, now several general practising consortia will be responsible (Black, 2010). Additionally, the control and responsibility will be passed to general practitioners instead of health service managers (Black 2010; Walshe 2010; Mahadkar et al. 2011).

Walshe (2010) and Mahadkar et al. (2011) argued that to re-organise the whole structure of the NHS would have huge transitional costs as a result. Furthermore, doubts of the statement of cutting managing costs up to 45% arose, since the NHS is willing to end 162 organisations and create 500-600 new ones. In addition, it is claimed that this structural change, would affect service performance, will distract the main aim of the NHS which is to treat patients with quality services.

Conflicting policy drivers and continuous transitions of services encountered questions of understanding the value of real estates. According to Mahadkar et al. (2011), not all Trusts were able to understand the various layers of services as to how they have been delivered. The '*Liberating the NHS'* paper suggested that *'the debate on health should no longer be about structures and processes, but about priorities and progress in health improvement for all'* (DH, 2010). The NHS Confederation emphasized that the *"policymakers still need to resolve the issue of transferring estates"*. Apart from some new buildings that are capable to cope to this changing scheme; most under the LIFT initiative, many buildings are old, crumbling and not fit for purpose (Fulop et al., 2005).

2.4.2 Distributing layers and optimal size

The issue of hospital size and how it could have an effect on the healthcare system has been captured in many articles. It has been observed that hospitals in Europe follow a reduction in bed capacity (OECD, 2012). To connect how the changes in government policy and infrastructure demand are linked, de Neufville et al. (2008) described a simplified top-down approach, with regards to the designing needs of a hospital. Initially, two pieces of information can be considered; firstly the number of patients and secondly the infrastructure resources required for their treatment.

The DH considers demand projections and then creates regional levels (Figure 2-3**Error! Reference source not found.**). This is one of the many models that have been proposed; also having an effect in the ways assets are used. At national level, this demand distribution approach could use some assurance whether existing assets have the capacity to accommodate a different distribution model which would help informing decision making.

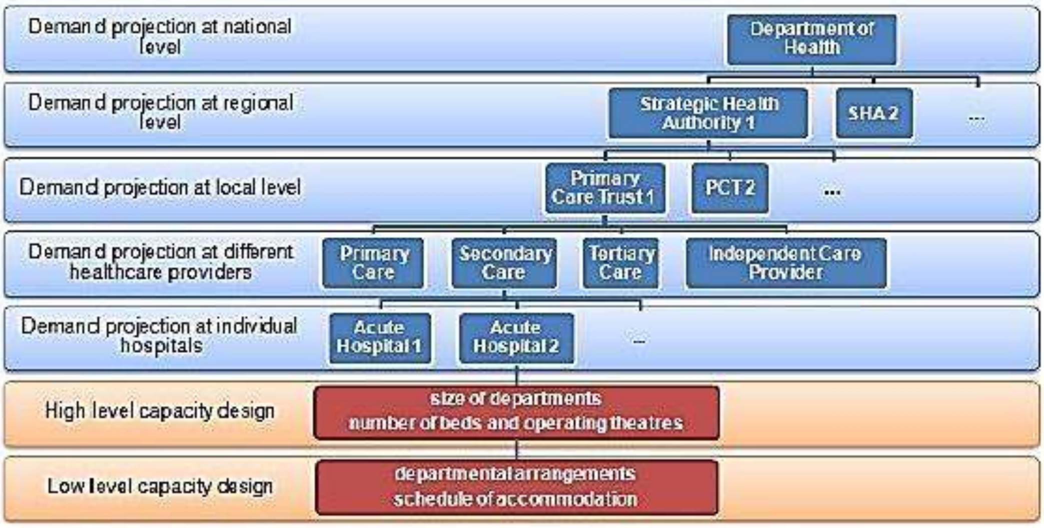


Figure 2-3: Key steps of a typical capacity planning process (de Neufville et al., 2008)

Various studies reach different conclusions about the optimum hospital size, because of the variety of different methods, constants and variables. However, most studies agree that in case there are economies of scale related to hospital production that range is between 200 and 620 beds (Posnett, 2002). This hypothesis is visually presented in Figure 2-4. Findings from Posnett (2002) suggested that the optimal scale of an acute hospital depends on two factors: the healthcare needs of local population (geographical dependencies); and the specialization care the hospital provides. Furthermore, in order to succeed on economies of scale regarding hospital size, it is required that medical, surgical and support services will be provided with minimum costs.

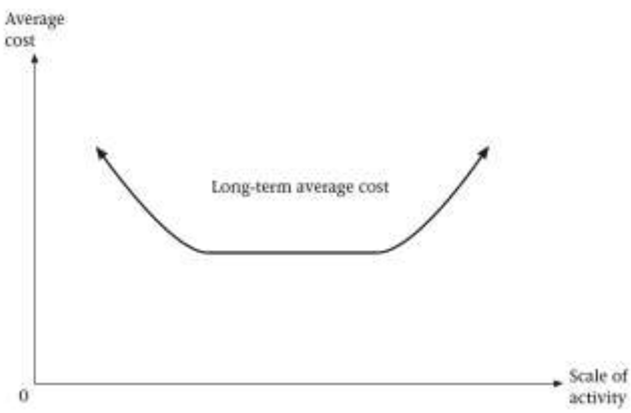


Figure 2-4: Observed long-term average curve (Aletras et al., 1997)

Also, average length of stay (ALS) is considered an important factor as it relies to the capacity of the hospital. The ALS in the UK is 7.5 days for the last ten years while the ALS for all other countries is 6.9 days. Another observation is that during the last ten years the ALS has reduced for all countries. McKee and Healy (2002) responded that though hospital bed capacity has been decreased, beds are being used to treat more and patients stay for a shorter time period.

The average percent occupancy for UK general and acute hospitals (1996-2010) is presented in Figure 2-5. Jones and Camberley (2011) highlighted that the average occupancy increased from 80.5% to 86.6% during the period 1997/98 to 2009/10 for the UK hospitals.

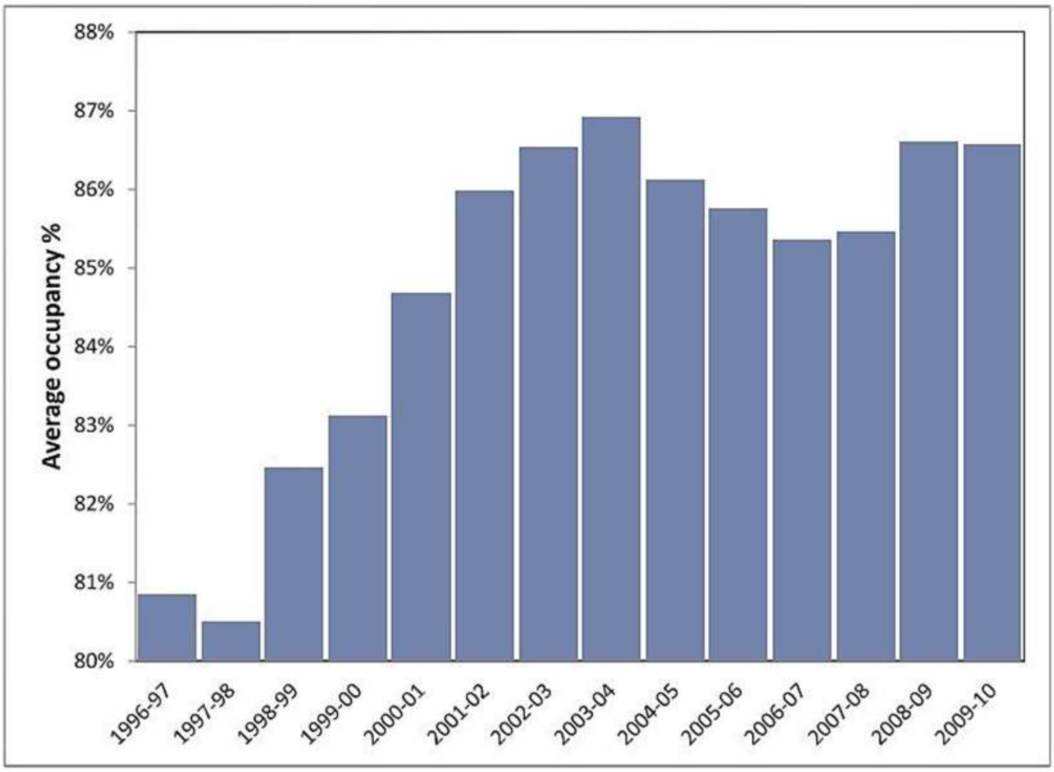


Figure 2-5: Average occupancy for general and acute beds in the UK 1997/8 – 2009/10 (DH, 2010)

Green and Nguyen (2001) determined that for more than 85% occupancy levels the results would bring unacceptable delays in clinical units that are relative small. On the other hand, large hospitals will succeed in achieving occupancy levels above 90% without affecting treatment.

Green and Nguyen's (2001) study proved that it is more beneficial to reduce the ALOS in terms of reducing required capacity than to reduce the ALOS (LOS). Seasonal period effects, such as influenza epidemics (Gorunescu et al., 2002) or more births in summer than in winter (Levine et al., 1990) may increase admissions and demand. For the latter case, managers can predict and prepare the unit for peak demand periods. In the former case, unexpected demands may occur, resulting inefficiencies in healthcare treatment. As a result a hospital may face risks in publics' expectations because it would not be able to cope to the emerging demands of the community.

2.4.3 Scenarios: a production of future projections

Lutz and Samir (2010) identified four different ways of producing future projections in forecasting to deal with uncertainty:

1. trust in only one projection and ignore uncertainty;
2. definition of alternative probability-free scenarios (brainstorming);
3. publish high, medium and low options concluding wide range of probabilities; and
4. provide fully probabilistic projections that conclude information about the range of the uncertainty.

The first choice is based on the most likely projection to happen. It can be applied in a relatively short time period and according to the authors, the costs related are negligible. This projection is not ideal to be applicable when making projections for a healthcare project.

The second option is a wider range of future projections often called scenarios. In capturing these scenarios various assumptions and data are collected. For example, in demography, trends in fertility, mortality and migration are a common approach to address these possible projections. The outcomes are a range of scenarios between the highest and lowest considered but the *"scenarios are generally considered free of probabilities with the only criterion being internal consistency"* (Lutz & Samir, 2010).

The third approach is more dynamic and accurate than the two previous in a way that it provides the reader *with "some range of uncertainty that can be interpreted intuitively"* (Lutz & Samir, 2010). An example of this approach was adopted in Wright (2010). Usually such projections could be admitted by governmental organisations. The variants are generated under three possible scenarios: high, medium, and low options. In assuming demographic trends for example the three variants would be fertility, mortality and migration. These trajectories would have high, medium, low options in a 'plausible range' of possibility. In this case though, uncertainty covers future fertility trends and is not associated with future mortality or migration trends. This is a simplified approach if for example the interest is on total population size.

The forth approach is the most accurate and complicated type of projection. According to Lutz and Samir (2010) only fully probabilistic projections are able to diminish the issues that arise by adopting the three above approaches. In this method, the uncertainty distributions are defined from the initial stages (Lutz and Scherbov 1998; Sanderson et al. 2004; Lutz and Samir 2010). Probabilistic projections are based on time-series analysis. Time-series analysis is a complicated approach that requires specifically data and that makes it difficult to find application (Lutz et al., 1997).

2.5 *Chapter Summary*

Summarising, there is uncertainty in designing facilities with dynamic requirements. As described in the previous sections, challenges using aggressive proactive approaches are raised. Forecasts on growth of population, optimising demand, or prediction of policy changes and requirements have left many healthcare facilities to become obsolete. The NHS is still clashing with increasing demands for consumers to be involved in their own care, pressures from funders for more financial accountability and changing technology in medical care. As a result, the nature and role of hospitals is undergoing upheaval.

As other researchers have argued (Kendall 1999; de Neufville 2008; Mahadkar et al. 2011) that structures emerge from the need in demand and the distributing layers of the healthcare system. It is necessary to create facilities that are relatively flexible and easy to adapt to meet the requirements of the evolving service needs.

Uncertainty in Healthcare

Findings from literature suggest that the focus of public, political and scientific concern is driving towards two things: global population growth and ageing population, making that a global concern for all healthcare planners. The demographic producers of those trends refuse to be clear on the level of uncertainty of their forecasts and as Lutz et al. (1998) pointed out they "*refuse to be precise about their subjective probability distribution*" and thus procurers and consultants should be prepared to design for uncertainty and allow change-readiness in their design solutions.

Chapter 3 Future-proofing Strategies

3.1 *Introduction*

In the previous chapter the uncertainty that characterises the design of healthcare facilities was identified. Various proactive approaches, such as forecasting, brainstorming scenarios and the application of building fixed structures, were reviewed and concerns were raised as to how effective they can be against uncertainty. In this chapter, the concept of future-proofing (FP) is introduced and further discussed as a 'shield' against uncertainty. The UK DH (2013) recognised 13 issues that need to be addressed at each project stage of a healthcare project regarding excellence in sustainability, one them being future-proofing (FP). In addition, the findings from the data collection identified flexibility and design standardisation as two very important tools of FP. Consequently, additional literature review was covered which discusses those two design methods. The benefits and challenges of adopting each method is discussed in this chapter.

3.2 *Holistic future-proofing*

In literature, the concept of FP covers areas such as protecting the built environment against climate change (Jentsch et al., 2008), FP buildings against future higher temperatures (Coley et al., 2012) and energy efficiency (Georgiadou et al., 2012). In addition, national and local frameworks have emerged, with a focus on effectively managing public health risks to achieve climate resilience (HM Government, 2013). Future-proofing has also been discussed as a dynamic system approach; and a conceptual framework has been set forth that focuses on the energy efficiency of the buildings (Georgiadou et al., 2012).

As discussed above, FP has often been presented as a process that deals with environmental and energy saving issues, but health care organizations are dealing with change in many more additional aspects. Criticality plays a major role in health care; unlike other types of buildings, health care buildings cannot afford major redesigning because of the impact this will have in the clinical service provision. From a client point of view, there are a number of procurement methods that would specify health care project delivery and thus how FP could be approached; all of them having advantages and disadvantages. Public – private partnerships and private finance initiatives (PFI) are commonly practiced in the UK for their long concession periods (Javed et al., 2014). Fast-track procurement is often a preferred option because of the overlapping ability to undertake delivery tasks. However, this comes with increased risks and costs (Bogus et al., 2006). Integrated project delivery (IPD) is branded as a non-traditional method where the teams come together early utilizing innovative technologies and thus collaboration is increased (Lahdenpera, 2012). As an alternative route, the client may choose the design–build type of contract but evidence has shown that these types of methods may bring confusion regarding the designer/contractor role (Larsen & Whyte, 2013). In order to increase building and operational performance, there is an increased number of clients which impose a soft landings framework in their tender documents where the supply chain is obliged to be involved after the handover of the project (Way & Bordass, 2007).

A list of FP tasks found in literature has been summarised in Table 3-1 and covers the whole range of phases occurring in a construction project; giving a holistic aspect of the concept of FP as it emerges in the built environment. Under the Column: Task; the tasks found in literature are grouped into FP objectives and according to project phase. Each FP task has been given a label (Column: Label) while the last column presents the source in which each task was found.

The FP objectives emerged from review of relevant literature and analysis of primary data and in essence they serve to categorise/group tasks with similar scope and aim and they are described in detail in Chapter 8[2]. Having a set of FP tasks from the literature, the interview sessions outlined in Section 5.6 where then used to identify additional tasks not mentioned in the literature, giving a more holistic aspect of implementing FP.

Table 3-1a: Selected literature of FP tasks aligned to project phases and emerged FP objectives

FP objectives	Tasks	Label	Source
Planning			
P-I: FP brief setting	Proposals addressing future services, and planning requirements	P1	(DH, 2013)
	Design brief includes plans for future change. Local	P2	(DH, 2013)

[2] *The emerged FP objectives have been used to categorise the list of literature and emerged tasks into groups that address similar issues/goals.*

	planning objectives are taken into account		
	Integration across hospital, community, primary, home	P3	(NHS Confederation, 2005)
	Reordering services in coherent processes	P4	(NHS Confederation, 2005)
	Financial, environmental, socio-economic considerations	P5	(Georgiadou et al., 2012)
P-II: Investment options	Redevelopment strategy to provide for future expansion	P6	(VHA, 2012)
	'No-regrets' options – investment and policy options that provide benefits even when no change occurs	P7	(World Bank, 2010)
	Higher 'safety margins' for change and uncertainty in socioeconomic development	P8	(World Bank, 2010)
	Potential developments across the area. Connections with transport, commercial activities etc.	P9	(de Neufville & Scholtes, 2011)
	Consideration of future developments based on future site alterations	P10	(de Neufville & Scholtes, 2011)
P-IV: Identification of flexibility	Broad descriptions of adaptability and flexibility (future end user behaviour, future changes of building layout, technology lock in, upgrades etc.)	P11	(Pati et al., 2008) & (Graham, 2005)
	Demonstration of FP on parts with different uses (core, movable, essential)	P12	(de Neufville, et al., 2008) & (Slaughter, 2001)
	Assess infrastructure regarding future developments	P13	(NHS Confederation, 2005)
	Planning of shell space design	P14	(Kendall, 2007)
	Flexible design to accommodate new equipment, technology, changing service models	P15	(VHA, 2012) & (de Neufville & Scholtes, 2011)
	Distinction of likely expandable spaces-not expandable to areas where expansion is allowed	P16	(VHA, 2012) & (Krystallis et al., 2012)
	Reversible and flexible options in case suggested concerns are wrong – insurance provision	P17	(World Bank, 2010)
	Weather-proofing Passive design strategies (e.g. high levels internal thermal mass, inclusion of solar heat gain, airtight construction, controlled ventilation, high levels of insulation)	P18	(Gething, 2010)
P-V: Awareness of government strategic framework	Awareness of government strategic framework	P19	(DH, 2013)
	Outperforming statutory minima (go beyond requirements of building regulations)	P20	(Georgiadou et al., 2012)
	Policy making for adaptation needs to be adaptive itself	P21	(World Bank, 2010)
	Preparedness for climate change (overheating, flood issues etc.)	P22	(Jentsch et al., 2008)
P-VI: Healthcare scenario factors	Best location of services based on patient pathways and models of care	P23	(Pati et al., 2008)
	Scenario analysis for long-term planning and assessment of strategies under a range of possible futures	P24	(World Bank, 2010) & (Georgiadou, et al., 2012)
P-VIII: Use of resources	Best use of people and infrastructure	P25	(NHS Confederation, 2005)
	Development control plan which tracks changes in service delivery	P26	(NHS Confederation, 2005)
P-IX: Whole-life assessment	Preventive maintenance plans	P27	(DH, 2013)
	Whole-life costing	P28	(Graham, 2005) & (Georgiadou, et al., 2012)
P-X: Knowledge systems	Participatory design through scientific and local knowledge	P29	(World Bank, 2010)
P-XI: Healing environment	Parklands, light, art, animals, social environments	P30	(VHA, 2012)
	Reduced ambient noise	P31	(VHA, 2012)
	Evidence based principles applied for well being	P32	(VHA, 2012) & (Price & Lu, 2013)
	Integrated information technology	P33	(VHA, 2012)

	Healing environment alongside reduction of resource consumption	P34	(VHA, 2012)
	Shared recreation and dining spaces	P35	(VHA, 2012)

Table 3-2b: Selected literature of FP tasks aligned to project phases and emerged FP objectives (continued)

FP objectives *(continued)*	Tasks	Label	Source
Design			
D-I: Demonstrating change-readiness of design	Circulation and service infrastructure suitable to accommodate change	D1	(DH, 2013)
	Buildings able to respond to climate change	D2	(Coley et al., 2012)
	Open-ended routes for future expansion	D3	(NHS Confederation, 2005)
	Main circulation routes to remain steadfast throughout lifespan	D4	(NHS Confederation, 2005)
	Shallow plan spaces	D5	(Kendall, 2007)
	Building systems having the ability to expand/contract	D6	(VHA, 2012) & (Brand, 1995)
	Soft spaces used as sacrificial in between hard spaces	D7	(NHS Confederation, 2005)
D-II: Demonstration of maintenance plans	Guidance on performing maintenance tasks	D8	(DH, 2013)
D-III: Demonstration of flexibility plans	Graphic demonstration of suggested flexibility and preparedness	D9	(DH, 2013)
	Demonstration of FP on different parts with different lifespans of the building	D10	(de Neufville, et al., 2008)
D-IV: Generic spaces & elements	Use of generic spaces rather than bespoke	D11	(Price & Lu, 2013)
	Built-in agility	D12	(NHS Confederation, 2005)
	Provision of generic rooms for range of health professionals to work	D13	(VHA, 2012)
	Long-term standard based structural frames and foundations	D14	(Gething, 2010)
	Group functions with similar requirements (multi-use)	D15	(Krystallis et al., 2013)
D-V: Design of disruption plans	Specification requirements for different zones of the building	D16	(Brand, 1995) & (Kendall, 2007)
	Ensure min. disruption of services for future upgrading	D17	(Georgiadou et al., 2012)
	Design for deconstruction	D18	(Brand, 1995) & (Graham, 2005)
	Potential change of construction and fixing detail on site	D19	(Gething, 2010)

Table 3-3c: Selected literature of FP tasks aligned to project phases and emerged FP objectives (continued)

FP objectives *(continued)*	Tasks	Label	Source
Construction			
C-I: Publication and application of FP	FP strategy published to contractors to avoid unprepared alterations	C1	(DH, 2013)

strategy on site	Necessary changes on site do not intersect with FP strategy	C2	(DH, 2013)
C-II:- FP working conditions	Working conditions-site accommodation	C3	(Gething, 2010)
	Temperature limitations for building processes	C4	(Gething, 2010)
Operation			
O-I: Awareness of FP strategy	Provision of as-built drawings to end users by the design team	O1	(DH, 2013)
	Estates managers are aware of FP strategy	O2	(DH, 2013)
O-II: Feedback from future-proof project	Buildings are assessed on regular basis for flexibility and adaptability. Findings are used for future developments	O3	(DH, 2013)
	In case of demolition, evaluation of FP strategy – lessons learnt	O4	(World Bank, 2010)
O-III:- Reuse of components and materials	FP strategy ensures reuse of materials	O5	(DH, 2013) & (Georgiadou et al., 2012)

3.3 *Benefits of being change-ready*

Habraken (2008) pointed out the issue of terminology with words such as ‘adaptability’, ‘flexibility’ and ‘polyvalence’. He argued that due to their multiple meanings, it makes it difficult to have a vocabulary accepted by everyone. Furthermore, in contrast to other professions such as engineering, medicine and law that define a precise vocabulary for internal communication, architects try to promote a personal or tribal vision of situations as they see them. After analysis of the literature, various types of flexibility have been identified and are discussed in this section.

The call for designs that accommodate flexibility is being driven by uncertainty. In fact, flexibility and uncertainty are in parallel worlds. Flexibility’s value is depended to the level of uncertainty a project carries. There would be no need for flexibility adoption, if designers did not realise that there are significant risks in a project’s lifecycle (de Neufville et al., 2009). In addition, Thomson et al (1998) concluded that healthcare facilities are *“dynamic organisations [that] must be supported by flexible space”.*

This study adopts Kronenburg’s (2007) definition which defines flexibility as a building’s ability to respond to ever changing situations. Such solutions can be used over increased or decreased demand. Flexibility is the proposed solution to *“contemporary problems associated with technological, social and economic change*” (Kronenburg, 2007).

The benefits of flexibility can be summarised as:

- extends the structures’ lifecycle in response to any scenario calling solution;

- developing better fit-for-purpose facilities;
- advances in technological innovations are more easily to adopt; and
- is more economically efficient and sustainable.

In the following paragraphs the above benefits are justified. Walker and Shen (2002) described the ability of the project management teams to exercise flexibility in construction in order to overcome unexpected issues. Key factors to this adoption are the ability of the construction to be flexible and the commitment to do so. It is important though to understand the complexity of the project itself as it is directly linked to flexibility. A flexible structure can be flexible only, if the design permits to.

Thomson et al. (1998) suggested that buildings should be able to respond to changes in organisational function and use their spaces appropriately. Walker and Shen (2002) described flexibility as dependent on organisations' and peoples' drivers and inhibitors. According to Blyth and Worthington (2001), the building is recognised by the organisations as an asset and symbol of culture and heritage. In the 1950s the American architect Louis Kahn proposed the 'without names' spaces and adaptability arose in a manner that *"a building is providing a range of spaces that through their quality and relationship stimulated use and commitment"*. Moreover Brand (1995) followed that argument and added that buildings should be able to adapt to their organisations' development and change.

Pati et al. (2008) argued that the planning for the future hospital lacks knowledge and whatever decisions will be taken by the stakeholders the solution should be, to be able for the structure to cope to as many options as possible. Flexibility deals with the building as a 'living entity' therefore the asset will be 'change-ready' at any period of its life to allow for emergent design solutions (Finch, 2009). Additionally, flexibility should be linked as a supportive element of sustainability. Regarding hospitals, choosing loose-fit design will promote flexibility to hospital designs and will increase its long-term efficacy in sectors such as financial, social and resource investment and ultimately healthcare facilities will become sustainable (Fawcett, 2012). 'Open Building' is an example of 'stock maintenance' practices that finds application especially in healthcare projects (Kendall, 2007).

The opposite approach to 'stock maintenance' practices (Section 3.4) is the 'scrap and build' practice. According to Caballero and Tsukamoto (2009), this practice has been criticized as not being sustainable and that it is a procedure that cuts the dialogue between the future and the past. Caballero and Tsukamoto (2009) argued that continuous change of the build environment (a 25 year old building in Tokyo is considered old) gives the chance to follow the latest ecological regulations and alternative energy supply systems. Furthermore, recycling of existing materials can add value to the sustainability plan but questions arise whether that is sufficient.

Supporting the benefits of flexible solutions, Olsson & Hansen (2010) discussed the importance of having 'room to maneuver'. 'Room to maneuver' takes a step back and allows space for future definitions of uses that will be addressed in the future of the asset's lifespan, while it is necessary that risks at the early stages of the project are sufficiently addressed. Additionally, such designs will deliver eventually reduction in lifecycle costs by allowing a well-timed and less costly response to dynamic requirements in projects such as healthcare projects.

Fawcett (2012) noted that a hospital in order to adopt flexibility as a design strategy should be designed to be 'tight free. The authors described 'tight fit' a hospital theoretically that is absolutely fixed to the initial design and consequently any future change is inevitable. In contradiction, a 'loose fit' design will be able to deliver to a hospital the flexibility that is required, allowing the organisation to implement its present activities and cope with any future changes. This approach *"would increase the long-term usefulness of the financial, social and resource investment in hospital buildings, and would be highly sustainable"*. Later in this chapter a distinction between 'tight fit' design and design standardisation is provided.

An equally significant aspect of flexibility should also be to understand how it *"can be incorporated into hospital design at low cost"* (Edwards & Harrison, 1999). Cremieux et al. (2005) characterised flexibility as a strategy that could help a business to maintain average costs despite changes in selected input prices through substitution of cheaper inputs. Flexibility can deliver reductions in the initial capital investment, justifying value for money as flexible solutions support the idea of 'less is more'. It is not necessary to build everything that might be needed from the start. That being said, considering the extra features that will enable the structure to adapt, the end extra cost will be often lower (de Neufville & Scholtes, 2011). Adaptable options in healthcare are essential and inevitable, as social trends, new technologies and new clinical techniques arise.

Adopting flexibility in the design stage can improve performance by 25% or more compared to standard approaches (de Neufville & Scholtes, 2011). It is necessary to decide the inputs that will be used in developing scenarios because as literature suggested (de Neufville & Scholtes 2011; Ford & Garvin 2009; de Neufville et al., 2009) approaches such as real options analysis are generally applied in an academic application rather than in practice. Therefore from a practical point of view adoption of such methods cannot be fully accurate and effective.

The decision inputs and how much 'room for maneuver' is allowed in relation to project time are shown in **Error! Reference source not found.**. The results of the study show the level of potential use of space to maneuver or design space in the early phases of a project (area A) as opposed to when the project is delivered (Area B) (Hansen & Olsson, 2011).

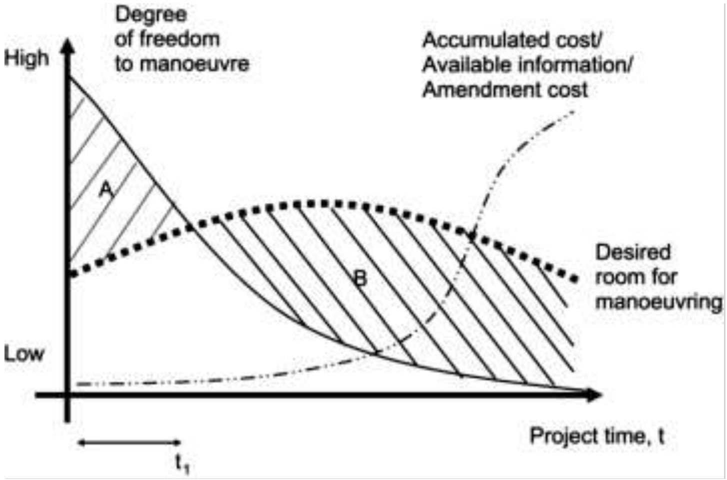


Figure 3-1: Consequences of different values of the uncertainty, significance of decisions and the degree of freedom to maneuver compared with the desired room for manoeuvring in different project phases (based on Eikeland 2001), (Hansen & Olsson, 2011)

Area A is the timeline when the project gains its greater opportunity for flexible solutions to be considered. Area B shows that 'manoeuvring' is reduced when the project goes past its early design phase. Also, the accumulated cost is increased throughout the project's lifespan representing how inefficient it is to make decisions around change when the project is past its operation phase. Thus, area B does not allow the design team to consider design for life solutions, failing to provide a future-proof product to their clients.

Additionally, Slaughter's (2001) graph (see **Error! Reference source not found.**), describes the different outputs of the standard designs as opposed to designs that accommodate change. A building's lifecycle increases significantly in the case of flexibility adoption but maybe more important is, that the cash flow over their lifecycle is in a continuous positive direction.

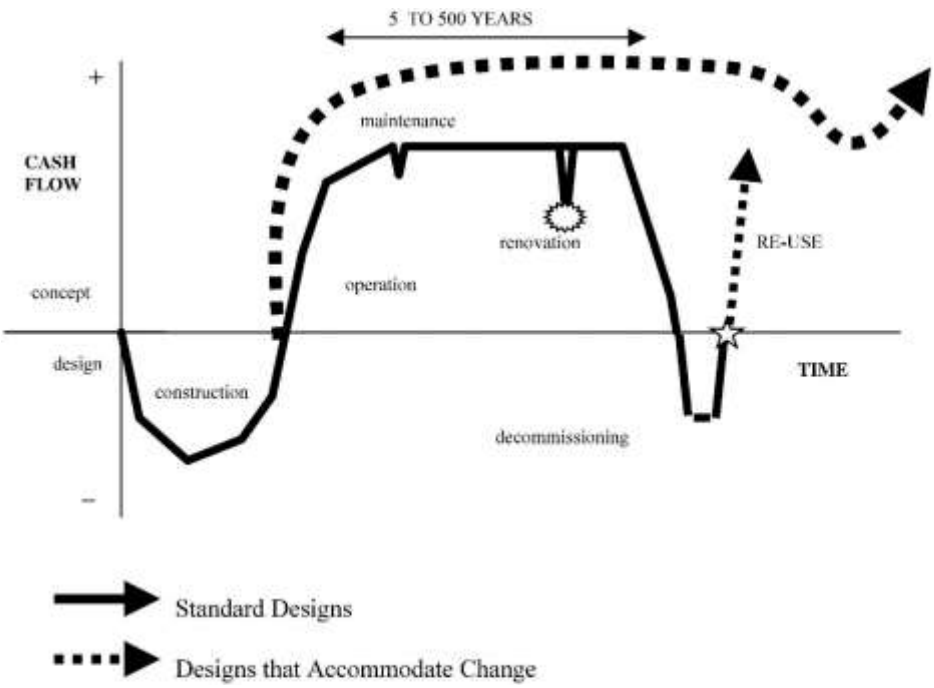


Figure 3-2: Expected lifecycle of facilities and potential impact of design to accommodate change (Slaughter, 2001)

From the owner's perspective, from homeowners to large corporations, concerns are raised whether their facilities will be characterized as obsolete. Slaughter (2001) argued that buildings with short functional life are less economical and lacking in resource efficiency. If a facility becomes obsolete in relatively short time, then it loses the opportunity to be efficient for the owner or the business that benefits from it. Finally, the building becomes even more profligate, as actions might be taken, such as expensive renovations or even demolition.

Blyth and Worthington (2001) described that the users' interest throughout the project will be in continuous adjustment, their purpose will be to keep options open so that business flexibility will be at its maximum level (see **Error! Reference source not found.**).

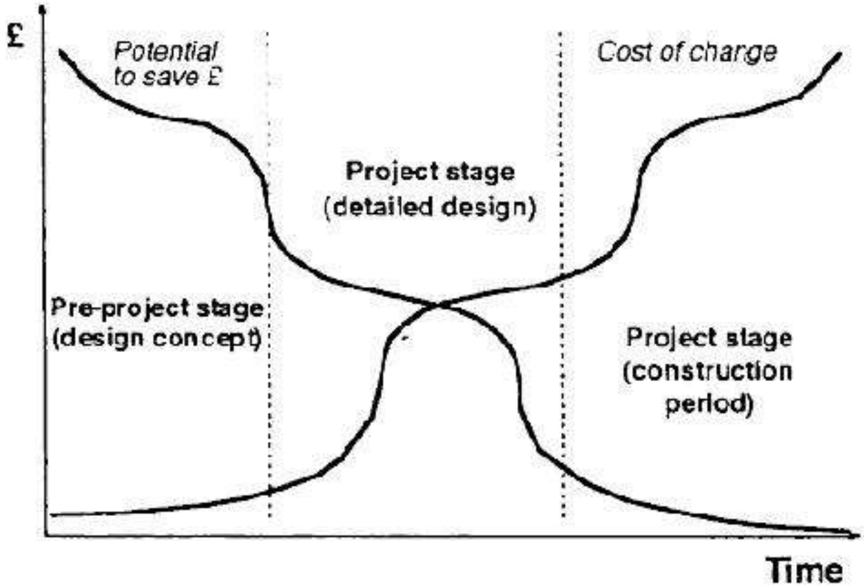


Figure 3-3: Effects of briefing by the various stakeholders at the appropriate time (Blyth and Worthington, 2001)

Time plays a significant role in the effective decision-making process for implementing an operative strategy. It is important to know when and what kind of decisions should be made. It is not strange to see conflicts between teams in decision making. Some teams may benefit from establishing decisions early in the project, while others will benefit if a decision will be taken later (Blyth & Worthington 2001; de Neufville et al. 2008).

According to Blyth and Worthington (2001) a successful design will benefit the project when the needs of design development and the needs of the construction contract meet the needs of the business. Lastly, the MacLeamy curve (**Error! Reference source not found.**) shows the industry's understanding that the further we are down the design process, the higher the cost of change will be.

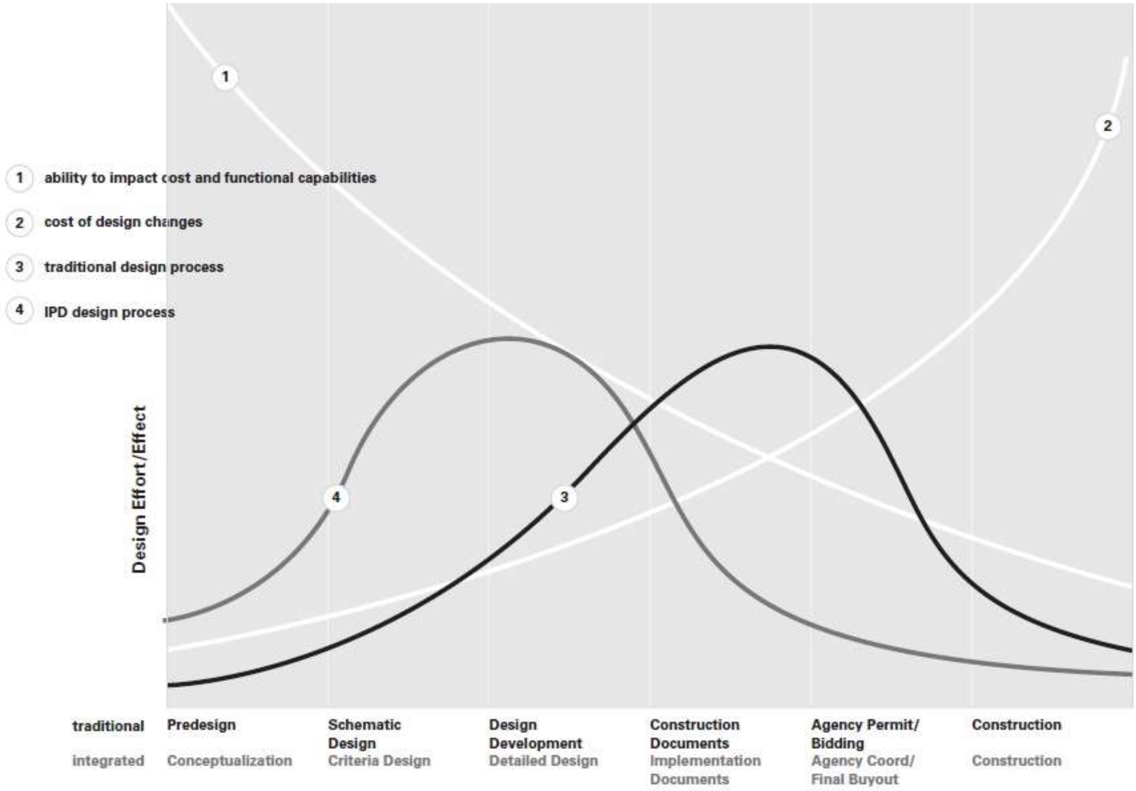


Figure 3-4: The MacLeamy curve – Comparison of traditional design process and IPD process and the cost impact of adopting BIM processes VS traditional CAD (AIA, 2007)

Findings from Blyth and Worthington (2001), Slaughter (2001), Eikeland (2001), and the MacLeamy curve (2004) as attributed in the Construction Users Roundtable (CURT) additionally presented that decisions in the early design stage of a project, can benefit at the maximum point all the stakeholders and decrease the cost of the project throughout its lifecycle. The above findings summarise the notion that by carefully planning and designing a facility so it could easily accommodate change, its functional life could be extended and the result will bring more profits to the organisation considering the traditional approaches of design and build. By carefully planning at the initial stages of the project, the teams ensure major cost benefits later. In contradiction, as the project advances to its completion, the potential for cost savings is reduced and the cost of applying changes is increased.

3.4 *Stock maintenance practices*

According to Slaughter (2001) *"a design approach can be defined as a goal or set of goals that a facility design should meet. A design strategy, on the other hand, is a specific means to accomplish an objective or set of objectives"*. Additionally Brand

(1995) argued that a strategy is designed to assist unpredictable changing situations. A strategy is the safety net that can provide room to manoeuvre. Slaughter (2001) categorised flexibility design approaches in the following three general approaches:

- Separating systems;
- Prefabrication; and
- Design for Overcapacity

which in addition they can be categorised under the stock maintenance practices Kendall (2005) described among others. Any of the above practices can be used as an approach to deliver future-proof solutions. Moreover, the above approaches can be used jointly on a project, depending its size and budget.

The first approach 'separating systems' is based on Duffy's (1990) initial proposal which was then refined by Brand (1995). Brand's (1995) 'shearing layers' have been widely used in research and construction. As shown in Table 3-4 different parts-layers of the building structure have different lifespans. Design for flexibility allows these layers to be replaced or changed over time in certain occasions. Evidently, *"the dynamics of the system will be dominated by the slow components, with the rapid components simply following along"*. This observation comes from an idea O'Neil R. (1973) expressed in his book '*A Hierarchical Concept of Ecosystems'* and led Brand (1995) to apply the same observation to the hierarchy of buildings. In short, the identified 'shearing layers' are mapped in the following order:

- the Structure is dominated by the Site;
- the Skin is dominated by the Structure;
- the Services are dominated by the Skin;
- the Space Plan is dominated by the Services; and
- the Stuff is dominated by the Space Plan.

The second design approach is 'Prefabrication'. Pre-assembly, prefabrication, modularization and system building are some additional terms that are used in the industry as well as in the research field to describe some form of standardisation (the concept of standardisation is described in following sections). Modular design supports standardised units or standardised dimensions to support construction (Waskett, 2001).

Table 3-4: Building Layers and time (Brand, 1995)

Layer	Description	Timescale
Site	Geographic setting of building	Eternal
Structure	The load bearing elements including foundations	30 – 300 years
Skin	The exterior surfaces that provide a weather protecting layer	20 years
Services	The working guts of a building – HVAC, electrical, plumbing, sprinklers etc	7 – 15 years
Space Plan	The internal layout – internal partitions, doors etc	3 – 30 years
Stuff	Furniture, equipment, personal positions of occupants	Daily

Prefabrication is described as an advanced construction technology and allows the building to be flexible in short time while keeping low costs. In Addenbrooke's hospital use of such methods were applied and significant time efficiency was noted (de Neufville, et al., 2008). Gibb and Isack (2003) documented the benefits of prefabrication from an owners' perspective (**Error! Reference source not found.**) and the results found Time being the first most significant benefit, followed by Quality and Cost.

A third approach is to 'Design for Overcapacity' as an approach to forestall future changes and needs. Adoption of this approach helps in cases were no replacement or extension of current capacity capabilities is welcomed; for example structural enforcement of the infrastructure for additional floors as a solution to accommodate future demand. This approach is not discussing expansion in terms of adding one or two floors; it rather focuses on major vertical additions.

A study by Guma et al. (2009) presented this design approach where major vertical expansion was used in four case studies. One of them was the 24 story, more than 81,000 m² expansion of the Health Care Service Corporation Building in Chicago. Findings from this approach revealed significant organizational and logistical advantages. The first phase concept of that project was only 30 stories above ground structure. That first phase was accomplished in 1997 and in 2010, an addition to the existing project was made and specifically 24 stories were added. Guma et al (2009) pointed out that for such kind of massive additions, both structural and operational designs must be carefully designed. Issues like current zoning and permitting laws and building codes should be checked otherwise vertical expansion will not meet permissions.

Table 3-5: Client perspective of the benefits of prefabrication (Gibb & Isack, 2003)

Benefit	Description (* indicates high incidence)
Time	Less time on-site—speed of construction*
	Speed of delivery of product
	Less time spent on commissioning
	Guaranteed delivery, more certainty over the programme, reduced management time
Quality	Higher quality—on-site and from factory*
	Product tried and tested in factory
	Greater consistency—more reproducible
	More control of quality, consistent standards
Cost	Lower cost*
	Lower preliminary costs
	Increased certainty, less risk
	Increases added value
	Lower overheads, less on-site damage, less wastage
Productivity	Includes less snagging
	More success at interfaces
	Less site disruption
	Reducing the use of wet trades
	Removing difficult operations off-site
	Products work first time
	Work continues on-site independent of off-site production
People	Fewer people on-site
	People know how to use products
	Lack of skilled labour
	Production off-site is independent of local labour issues
Process	Programme driven centrally
	Simplifies construction process
	Allows systems to be measured

Others have also proposed similar approaches which deal with uncertainty. Brand (1995) argued that scenario planning (SP) has become so turbulent that traditional forecasting methods seem inadequate.

Scenario Planning can provide different directions and options of different assumptions. It helps the design team explore the future environment from different angles. Scenario Planning is suggested to bring important assumptions as to what is required to be considered for the design decision of the building; in other words, implementing a planning approach of possibilities of different parts of the building that could be able to change at different levels providing value for money and to be more valuable as a construction (Francis, 2010).

Francis described that SP can be a powerful technique that can be used for decomposing complex structures such as healthcare facilities, to semi-independent components analogous to its many functional parts. The planning of each component can be treated more independently regarding the other parts. Correspondingly, there is no necessity to expect that the decomposition of the complete design into functional components is an absolute process. In important circumstances there may exist alternative feasible decompositions, hence divisions by sub functions, sub processes or sub areas may occur (Simon, 1996).

3.5 *Design standardisation in healthcare*

Standardisation means different things to different people. In healthcare, standardisation is discussed in various terms. The UK Government and building industries addresses standardisation from many aspects some of them are focusing on procurement methods such the Procure21 and recently the Procure21+ procurement framework which is designed to *"improve the procurement process for publicly funded schemes and create an environment where more value could be realised from collaboration between NHS Client and Construction Supply Chains"* (NHS, 2011). Additionally, the Health Building Notes (HBN) (DH, n.d.(a)) is another effort by the DH to identify the best practice standards in the planning and designing phases of healthcare facilities. The series identifies specific and/or service requirements and inform the design and construction teams. Other series of publications have also been released to support best practices. The Health Technical Memoranda (HTM) (DH, n.d.(b)) identify healthcare specific standards for building components as well as the design and operation of engineering services. The Activity Database (ADB) (DH, n.d.(c)) is another release, this time a software tool that is used as an add-on in BIM platforms and contains information for briefing, design and commissioning for new build and refurbishing healthcare buildings in acute and community settings. Standardised spaces are generally accepted to support process and workflow, and consequently they should improve performance and productivity (Price & Lu, 2013). Reiling (2004) stated that with standardisation, processes should be more reliable and simplified; it also reduces reliance on short-term memory and it promotes an average process to be followed by those unfamiliar with the surrounded environment to achieve work safety and efficiency.

3.6 *Chapter Summary*

The chapter covered the concept of Future-proofing (FP) as a proposed solution to dealing with uncertainty in delivering design for life solutions. This study takes an opposite stance from past approaches that deal with uncertainty and proposes FP as an approach that delivers solutions with 'room to maneuver' that respond to change. Literature has identified FP as part of sustainability strategies and particularly as a response to achieve environmental benefits. It is the intent of this study to present FP as a response to the challenges healthcare organisations face, particularly with regards to managing their assets against change.

As part of a successful future-proof project, flexibility, the main element of FP was discussed and various aspects of flexibility where discussed, both as a design approach and as a design strategy. The benefits of discussing flexibility at early stages where justified. Flexibility is discussed in a broaden area within the literature; organisational flexibility and flexible design are some of the many faces of flexibility. This research is discussing flexibility by means of identifying possible solutions that can be accommodated into one whole-life BIM model. From this aspect, flexibility can manage to increase opportunities and limit risks regarding the lifespan of a healthcare project.

Finally, the concept of standardisation was discussed; mainly to complement the findings of this research. In the following chapters it is revealed that when standardisation is implemented as part of good practice, it is as essential as flexibility in achieving FP. Limited research has shown that standardisation can benefit complex environments such as healthcare facilities and thus further research would seem beneficial.

Chapter 4 Investigation of BIM growth

4.1 *Introduction*

Literature review in this chapter investigates the concept of Building Information Modelling (BIM). BIM, a data driven approach in the construction sector, is a mechanism that focuses on the digital side of the asset. The industry has recognised that in addition to delivering and managing physical assets, there is a requirement to accommodate the delivery and management of the digital side of the assets. Hence, it is crucial that FP is considered from this standpoint.

BIM is explored in three fields: Policy, Process and Technology. In the Policy field findings from research and governmental initiatives regarding guidelines, and standards are discussed. In the Process field best practices and workflows that are applied in the industry are identified and lastly in the Technology field an overview of technology achievements that are utilised to implement a BIM process are discussed. Particularly the UK BIM Strategy is discussed and in addition how the UK industry is adopting this new process workflow of sharing data is presented in more detail.

4.2 *Brief background of the BIM initiative*

Various Governmental Initiatives have been formed globally aiming to introduce BIM to the industry and promote guidance for all disciplines involved in building and infrastructure projects. The Singapore Government introduced in 2012 the BIM Steering Committee which in turn produced a series of BIM documents that describes what BIM is, how organisations can adapt their processes and then provided a series of BIM 'manuals' and thus each discipline could use as a template to start preparing their internal BIM strategies (CORENET, 2015). The US have been one of the earliest BIM supporters and particularly the National Institute of Building Sciences alliance (NBIMS) (National Institute of Building Sciences, 2015) has produced a series of standards about BIM guidance and the first BIM standard - which laid the foundation for the forthcoming BIM standards - was released back in 2007. Other adopters such as the Bavarian Government FM Handover IFC Model View Definition (OpenBIM, 2013) are working collaboratively with companies such as

Autodesk to exploit Open BIM and specifically resolve interoperability issues using Industry Foundation Classes (IFC) models.

BIM is proposed to be the vehicle that progresses future-proofing (FP) through information processes. There is a global interest in the adoption of BIM processes and specifically the UK Government is aggressively aiming towards that goal. Regarding the healthcare construction in England, this is set forth by the DH in collaboration with the Procure21+ (P21+) Principal Supply Chain Partners. This partnership has recognised that IT and specifically design computing has increased the expectations of provision assistance to the project team.

4.3 *Planning of BIM and achieving process maturity*

In this section BIM planning is articulated from a policy perspective. This is a discussion of how to organise the process of BIM and what processes have to be considered prior to starting the modelling process. Within the industry, we have seen many stakeholders of the supply chain focus on the 3D model (object-oriented) rather than the process-oriented, though it is recognised that it is *"the process that determines the requirements (characteristics) of the model objects*" (Kymmell, 2008). Having considered the various processes that need to be addressed first, it is also reasonable to look at the actual modelling process later.

The BIM Plan should be developed as early as possible. The BIM execution is continually progressed as additional participants are joined to the project. The planning team is responsible to monitor, update and revise the planning of the project as needed. In short, *"the plan should define the scope of BIM implementation on the project, identify the process flow for BIM tasks, define the information exchanges between parties, and describe the required project and company infrastructure needed to support the implementation"* (CICRG, 2010)

It is important to highlight that the planning of BIM is the preparation for the implementation of the BIM process (Kymmell, 2008). In this respect, the following questions should be satisfied

- What is the nature of the project?
- What is the desired procurement method?

- What are the deliverables of the simulation?
- What difficulties should be addressed (project, process related)?

Moreover the *'BIM Project Execution Planning Guide'* (CICRG, 2010) outlined a four step procedure for delivering a BIM Project. The procedure is designed to support owners, programme managers and the supply chain (i.e. consultants, facilities management team) that participate in the project from the initial stages of the conception to operation and maintenance of the project.

In short, the four steps outlined in the BIM Project Execution Planning procedure are (Figure 4-1):

1. identify the BIM goals and uses of the project - what needs to be modelled and what information needs to be part of the simulation?;
2. design the BIM execution process - a BIM process map of the *tasks* the team members have to complete;
3. develop the level of detail each member has to complete in order to *exchange* the information being created; and
4. identify the project *infrastructure* to successfully implement the plan.

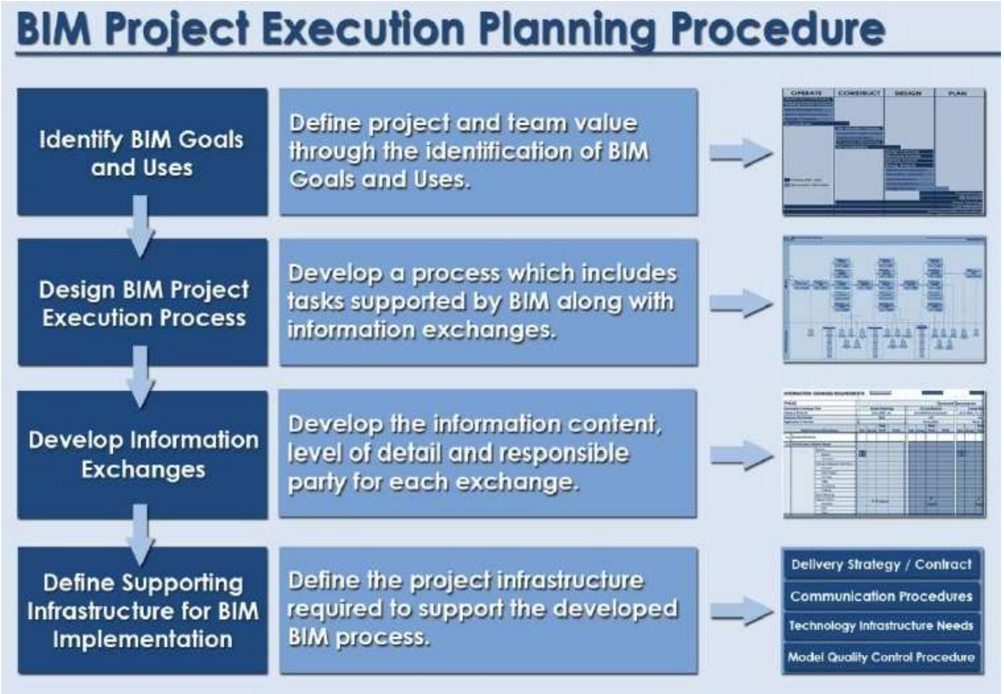


Figure 4-1: The BIM Project Execution Planning Procedure (CICRG, 2010)

In order for the BIM Plan to start, the planning team should be formed to deliver the project; the owner, designers, contractors, engineers, major specialty contractors, facility managers, and the project owner have to be identified as early as possible (CICRG, 2010). The team is then subdivided into two categories: the primary participants; and the key supporting participants. The distinction of a member as to which category belongs depends on its importance and evolvement throughout the project's lifecycle. In this stage, the BIM goals and uses of the project are captured and further planning initiatives are starting to be shaped too until the planning of the project becomes concrete.

Based on the aforementioned, the *'BIM Overlay to the RIBA Outline Plan of Work'* suggested the following objectives for BIM planning to be followed from the early design stage of the project:

- identify owner's aims and objectives;
- development of feasibility studies;
- develop requirements and constraints based on owner's needs into the Design Brief;

- identify procurement method, project organisational structure (participants, BIM procedures);
- implement the Design brief with additional data;
- preparation of Concept design including outline solutions; and
- development of concept design using project BIM data.

The basic assessments that are being covered during the conceptual design are specifications that cover spatial area, functions, types of construction and economic viability. After the building's program elaboration, the project's building layout is generated. Floor plans, masses and general outlook, determine the facility's orientation on the site. Its structure and environmental quality can be discussed. According to Eastman et al. (2011.) at this phase of the project the team will be able to determine initial costs, delivery time and other critical aspects that affect the project.

At the same time, the team should determine the desired procurement method and furthermore it is important to contemplate how this delivery method will affect the implementation of BIM on the project. In this respect, the team can choose to implement their project by adopting IPD, Design-Build, Design-Bid-Build or any other procurement method that satisfies the owner and the stakeholders. All delivery methods can be implemented with BIM and it is also documented by many researchers that the ultimately goal for BIM maturity is IPD (AIA 2007; CICRG 2010; McCuen & Suermann 2007; RIBA 2012). A visual explanation of BIM maturity steps and stages is presented in Figure 4-2.

Figure 4-2: BIM maturity is subdivided into three stages - linear view (Succar, 2009)

Prior to the inception of Integrated BIM, other technology roadmaps had been proposed. The '*Strat-CON roadmap'* and the *'FIATECH Capital projects'* are two examples. To these roadmaps, Kiviniemi (2009) argued that Integrated BIM was just a small part of those roadmaps. Moreover, Kiviniemi (2009) highlighted that it is important for the industry to identify the key obstacles and drivers, in order to accelerate the development of its processes and technologies. Additionally, a distinction of two categories was described to be the reason of the slow adoption of BIM implementation in the process field: the *human barriers* and the *technical barriers*.

On the human side, the main barriers that were identified are old processes, business models and contracts. New standard processes and contractual models for the use of integrated BIM are developed and deployed. This means that the participants of such methods should gain knowledge of the BIM implementation and that education for BIM should be enforced.

Regarding the technical barriers Kiviniemi (2009) argued that the problem depicts in the insufficient quality of software support for data exchange, namely interoperability. On central concern to the future of UK Construction Sector regarding the adoption of BIM, the purpose of the '*B/555 Roadmap'* is to document and describe the activities of the British Standards committee to reach the HMG BIM strategy 2015 maturity goal (Figure 4-3). The concept of maturity levels has been defined to simplify the description of BIM technologies as well as the proposed processes. Moreover, the deliveries are related to the suitable maturity level to aid clarity of application within the process field players. The maturity levels are defined as such:

- *Level 0*: use of 2D CAD technology, and exchange mechanism of data most likely in paper or pdf, unmanaged share of information;
- *Level 1*: use of 2D or 3D CAD technology, guidance under BS 1192:2007, collaboration within a common data environment, no integration of cost management;
- *Level 2*: all disciplines produce their own 3D models and share them in a CDE. Design information is exchanged through a common format and all information combined leads to a federated model; and

- *Level 3*: fully open process and data integration is enabled (IFC/IFD), all information is located in a model server; this stage of collaboration is referred iBIM or integrated BIM as well.

These maturity levels which are proposed by the policy bodies are in their majority influenced by the power of Technology. It is also important to note that the Process field is stimulating both fields (Policy and Technology) and thus these two fields redeploy to provide the process actors with the 'right instruments' in order to be able to deliver advanced engineered and efficient solutions.

Furthermore, the three inter-related issues of Sustainability (of which future-proofing is part of); BIM; and procurement methods have drawn significant interest and therefore are in the research agenda of the UK Government Construction strategy. The UK Government is underway running pilot projects in order to utilize contractor-led procurement and to investigate how the construction can move easily from one BIM maturity level to another until reaching the ultimate goal: IPD. The requirements for that adoption focus in the adoption of industry-wide processes (instead of professional or practice exclusive), the identification of the right project team and the selection of the right form of procurement that will support collaboration and innovation (RIBA, 2012). The more recent strategy report for 2025 stated that *"only through the implementation of BIM will we be able to deliver more sustainable buildings, more quickly and more efficiently"* (HM Government, 2013).

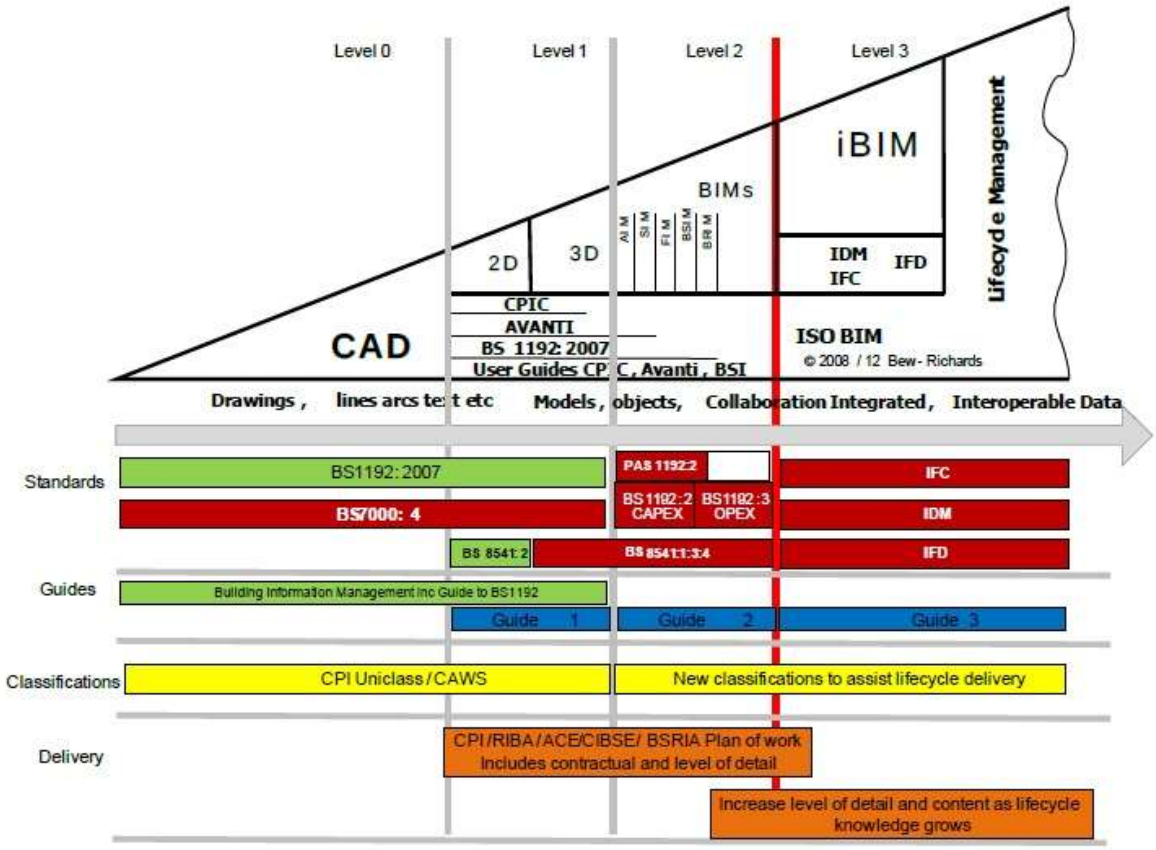


Figure 4-3: The maturity model with articulation of the standards and guidance notes (British Standards Institute, 2012)

4.4 *The 8 Pillars of BIM Level 2*

In the UK, the BIM task group (http://www.bimtaskgroup.org/) is the appointed group to *"drive adoption of BIM across government"* according to the Government Construction Strategy (Cabinet Office, 2011). In the following paragraphs the UK initiative for BIM is outlined.

Pillar 1: PAS 1192-2 outlines the information delivery workflow. The disciplines when producing information should have a 'beginning with the end in mind understanding' and the purpose of information are to be used throughout the project's lifecycle. The information (green) and the project management (blue) processes are shown in Figure 4-4. In BS 1192:2007 standards and processes for delivering project outcomes (BIM and non BIM) are explained, while in PAS 1192-2 only information specific to BIM are described.

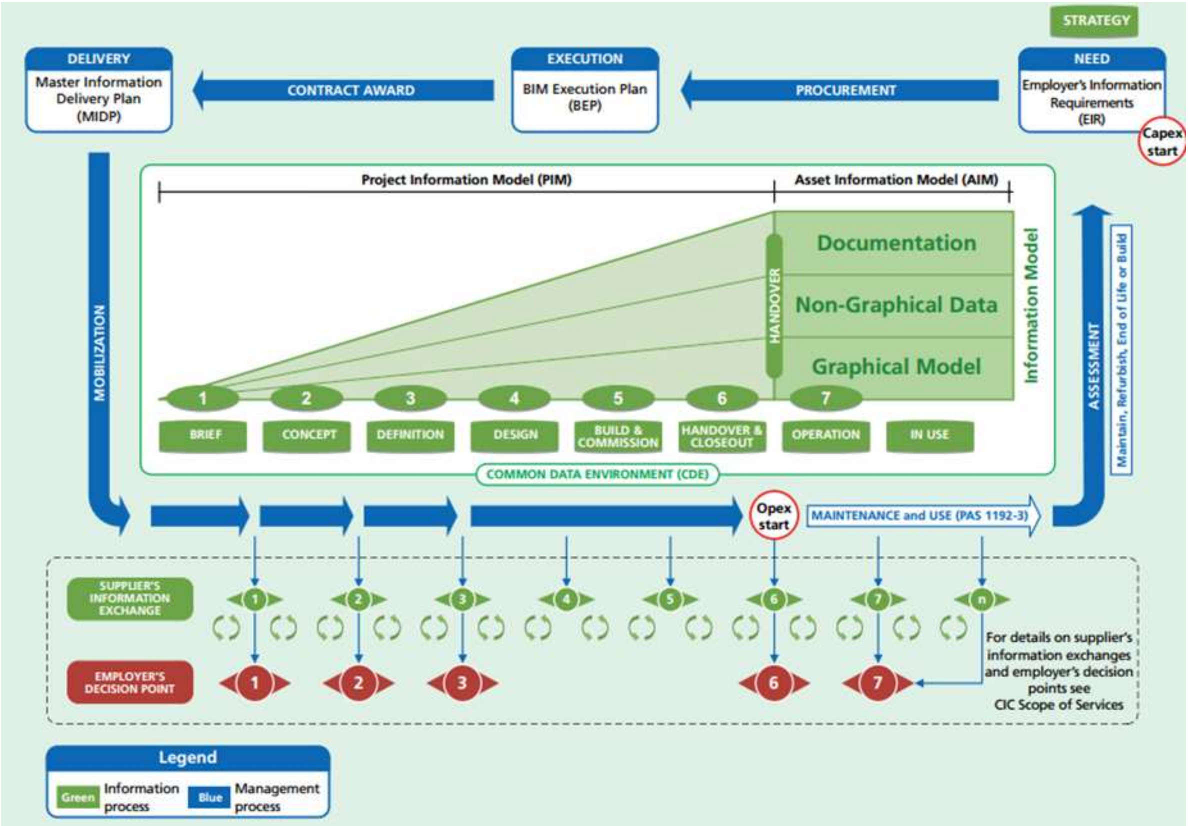


Figure 4-4: Information delivery cycle (BSI, 2013)

Pillar 2: The PAS 1192-3 (BSI, 2014) document *"focuses on the operational phase of assets irrespective of whether these were commissioned through major works, acquired through transfer of ownership or already existed in an asset portfolio"*. Facilities management and Asset management are activities for managing key assets of an organisation in terms of whole-life costing. These activities cover physical, organisational and people related requirements. The PAS 1192-3 document focuses on the physical requirements. The relationship between the Project Information Model (PIM) and the Asset Information Model (AIM) is presented in Figure 4-5. The AIM is defined as *a "single asset, a system of assets or the entire asset portfolio of an organisation"*. Asset Information Requirements (AIR) is the "*data and information requirements of the organisation in relation to the asset"*. Organizational Information Requirements (OIR) is *"data and information required to achieve the organisation's objectives".* The above are summarised in Figure 4-5.

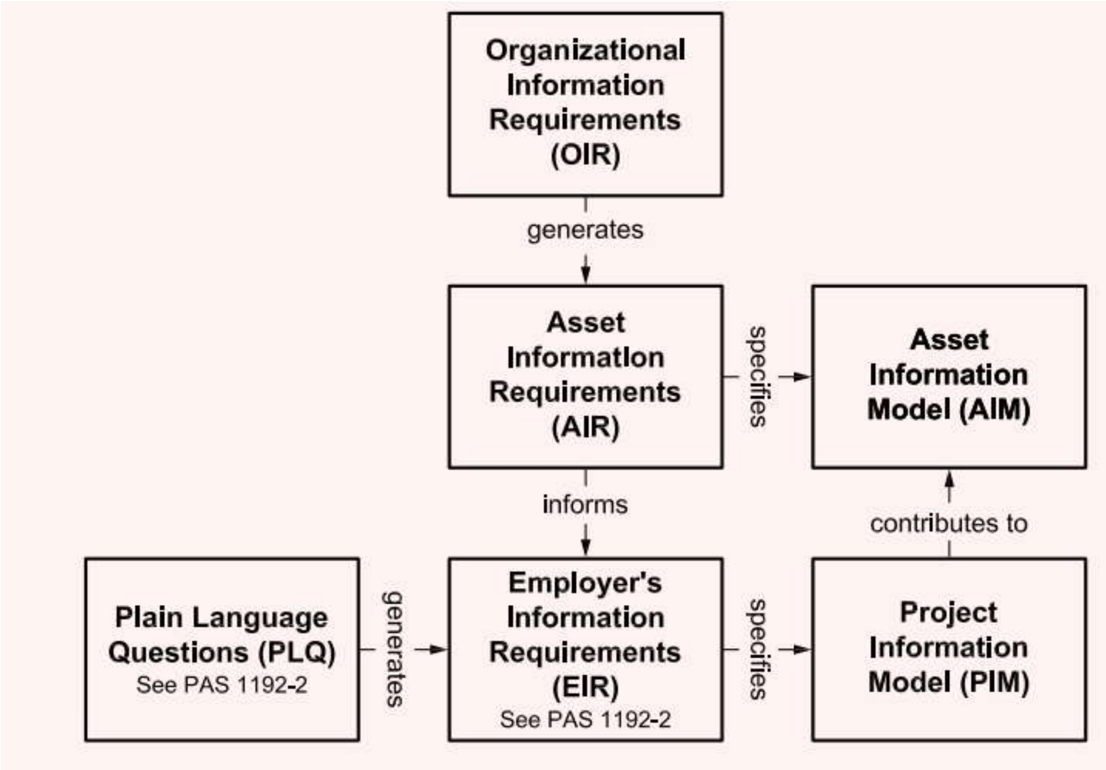


Figure 4-5: Relationship between PAS 1192-2 and PAS 1192-3 (BSI, 2014)

Pillar 3: Construction Operations Building Information Exchange (COBie) is the information exchange scheme for BIM level 2. It defines a checklist regarding the transfer of information between different disciplines. COBie is an internationally recognised data exchange standard, where design and construction teams can exchange buildings systems information with their Clients in a standardised format for delivering construction handover data. The COBie scheme *"holds information about the spatial locations and the equipment and components that make up the facility"* (BSI, 2014).

Pillar 4: PAS 1192-5 relates to cyber security and digital security. This document is meant to be used as a protection standard that will prevent stakeholders outside of the project to have access to the data that is produced.

Pillar 5: The BIM Protocol (CIC, 2013) is a supplementary legal agreement that is expected to be incorporated into all direct contracts between the Client and the Project Team Members.

The key principles of the BIM protocol are:

- all members that are responsible for the delivery of BIM models should have a BIM Protocol incorporated into their contract/appointment;
- the BIM Protocol cannot be amended;
- the Protocol provides specifications on Intellectual Property;
- any changes to the Protocol and its Appendices during project development should be treated as variations to the Contract;
- all BIM models should be clearly stated in the Model Production and Delivery Table (MDPT), while the MDPT is part of the contractual agreement;
- liability is assured for use of the models; and
- the Protocol includes a provision that the model can be passed on (e.g. from a discipline to another discipline or client).

Pillar 6: Government Soft Landings (GSL) is the proposed approach for ensuring smooth handover from design and construction to operation and maintenance. A GSL champion for the project is proposed to be the person driving the process ensuring on-going maintenance and operational cost is reduced throughout the lifecycle of the project. The GSL ensures training, commissioning and handover is provided at early stage to end users to achieve optimal performance. In the industry this is usually a three year process which focuses on educating the users about the use of their facility (efficient use of MEP systems etc.)

Pillar 7: Digital Plan of Work (DPoW) is an online tool proposed to make more efficient the RIBA Plan of Work and essentially will allow all project teams and the client to keep pace of what has been achieved and when. The DPoW is a toolkit where information can be captured, validated, and stored and be in accordance to BIM level 2 standards.

Pillar 8: A Classification system is the last of the Pillars and this can be used for organising information throughout all elements of the design and construction process providing a structured package for the Asset Managers to manage their assets. Examples of Classification systems are the Uniclass 2, the New Method of

Measurement (NRM) codes etc. In addition, Major Clients (for example HS2) are developing their own standards to classify their assets (AD[4]).

4.5 *BIM for Future-proofing the Healthcare Built Environment*

Research on ecological landscapes suggested that institutional and organisational landscapes could be approached the same way, in order to contribute to the resilience of socio-ecological systems (Olsson et al., 2004). Most of the features found in Olsson et al. (2004) can be applied in today's construction 'ecosystem' too and moreover, information workflows, collaborations and interacting communication platforms are done via embracing BIM solutions. BIM is the process encompassing the generation, management and communication of digital information about the design, construction and operation of the built environment, as well as the technology to support this process. For design, BIM signals a paradigm shift from drafting to modelling, which enables design decisions to be made with more foresight. The UK Government's Construction Strategy, which mandates BIM use by 2016, envisaged the adoption of project-specific 'common data environments' as part of Level 2 BIM Maturity. Increased collaboration throughout all project phases should be achieved and the construction industry should be able to produce data beyond project handover. An example of asset management with BIM is PAS 1192-3 (BSI, 2014), and the more recent BS 1192-4 (BSI, 2014), which discuss the use of COBie data management for the exchange of information throughout the lifecycle of a facility.

In healthcare construction, an example where facility and clinical information are linked to support managing healthcare facilities was presented in Lucas et al. (2013). Innovative engagement processes as part of a BIM based solution was used for enhancing decision-making in healthcare facility management (Irizarry et al., 2014), while a healthcare related problem scenario where BIM and healthcare specialist software ActivityDatabase are used concurrently on a refurbishment project was presented in Krystallis et al. (2013). It seems that healthcare is a sector where BIM can be exploited in many more innovative ways.

BIM was described *as "an IT-based approach that involves applying and maintaining an integral digital representation of all building information for different phases of the* *project lifecycle in the form of a data repository"* (Gu & London, 2010) *and "BIM refers to a set of interacting policies, processes and technologies that generate a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle."* (Succar et al., 2012). The above characterisations present the aspirations of using BIM in construction for lifecycle purposes, yet the application and evaluation of actually using BIM in healthcare for such purposes still requires answers.

4.6 *Chapter Summary*

In the remainder of the study an attempt is made to identify the interrelationships that exist between BIM and FP. The following points of departure have been summarised. There seems to be a lack of systematic investigation between FP and BIM. It seems that additional evidence are required to explore whether FP and BIM are dependent on one another and if they are, then to what extent. BIM is a research topic that is still under development. Within the existing body of literature BIM is approached and measured as a solution for many issues in construction management and in the near future, many more approaches will be tested against BIM. This only shows that there is plenty of space which will investigate the potential of what BIM can do and how it can better be exploited.

There is little research evidence relating to the impact of space standardisation and BIM on healthcare delivery. Standardisation is mostly discussed in BIM literature in terms of interoperability, which is concerned with product-model data exchange in project communication. Thus, this study investigates the effect of design standardisation on practitioners who design and deliver projects through BIM processes.

For a project that is required to be future-proofed, early design stage this is the most important stage. BIM allows a construction project to be controlled through a database (data-based process) that accepts information from a variety of sources from the earlier stages of the project.

Chapter 5 Research Methodology

5.1 *Introduction*

Following the framework of research design developed by Creswell (2009), this chapter describes the procedures that were taken into consideration to meet the research goal. The selected approaches based on this framework are identified and their selection over other approaches is justified.

5.2 *Framework of Research Design*

There are three research approaches: qualitative, quantitative and mixed methods. A study might be more qualitative than quantitative and vice versa. The framework focuses on three aspects of research design. In the first aspect the researcher defines the *paradigm* of their research. A paradigm is used to inform and guide inquiries. For the second aspect the researcher clarifies the selected *strategies* of inquiry that will be adopted to conduct their research. The third aspect takes into consideration the *methods* adopted by the researcher, namely to collect, analyse or interpret the data. For each aspect the researcher has to identify and elaborate the method used for each cause. The framework of the research design is presented in Figure 5-1.

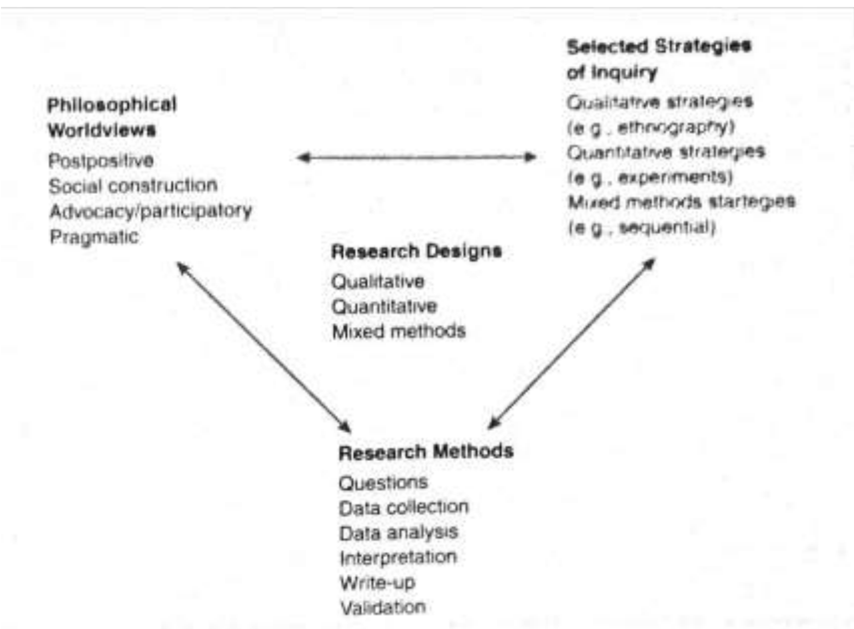


Figure 5-1: Framework of research design (Creswell, 2009)

5.3 *Selected Research Design*

The aforementioned discussed framework in in Section 5.2 was used to set out the design of this research. The application of BIM as a construction strategy is relatively new within the built environment, various approaches need to be invoked in order to support and understand the exploitation of the subjected enquiry. Fitzgerald and Howcroft (1998) articulated the tension between the 'hard' positivist (quantitative research design) and the 'soft' Interpretivist (qualitative research design) research philosophies in the field of Information Systems/Information Technology which also this research has its place. After two very entertaining and abrasive tales-examples of both philosophies they argued that neither approach has a "*monopoly on poor research"*. Both approaches have weaknesses and limitations; consequently expecting a researcher to choose one approach over another seems unjustifiable. Research conclusions will be more robust if researchers are aware of the strengths and potentials that they can obtain from the use of both approaches and not as Fitzgerald and Howcroft (1998) noted, researchers from one perspective to be ignorant of the strengths that can be obtained from the other field.

The nature of each objective, as described in Section 1.5, implied that more than one research methods would be appropriate for this study. From the aforementioned philosophical and methodological standpoints, the *Multiphase Design* (Creswell & Clark, 2011) seems to be more appropriate for such complex situations. This design is adopted when the researcher examines a problem through an iteration of connected strategies that are sequentially or/and concurrently aligned, and each new strategy builds on the conclusions of the previous one to inform the overall objective of the study.

5.4 *Selected Paradigm*

Paradigms or worldviews are basic belief systems based on ontological, epistemological, and methodological assumptions (Guba & Lincoln, 1994). They are used to justify why the researcher chose qualitative, quantitative or mixed methods approaches. In his book '*The Structure of Scientific Revolutions'* Kuhn (1970) defined a scientific paradigm as *"universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of researchers"*. Consequently, Paradigm is the theoretical framework which is used as a lens to describe the system by which researchers view events. As such, a paradigm not only determines from which view the problem is questioned, but also the approach of questioning and discovery (Fellows & Liu, 2003). Paradigms are described as basic beliefs in a sense that though they must be used and be well-argued by the researcher; they must also be accepted on faith because there is no way to prove their ultimate truthfulness (Guba & Lincoln, 1994).

The subject of this research is the Built Environment and the use of data to inform decision making that is invented to support the project team and allow the client to make better decisions considering / recognising future uncertainty about their assets. As such, the *Interpretivist* worldview was adopted.

The Interpretivist paradigm involves philosophical ideas which are adopted especially in management and other social sciences and indicate that reality is formed by the participants. Here, reality is constructed socially, there is more than one reality and the 'scientific research' is depended on both time and context (Fitzgerald & Howcroft, 1998). Usually such approach is adopted in a qualitative research. Researchers in this approach are asked to 'see' through the eyes of the participants who observe. *"The researcher's intent is to make sense of (or interpret) the meanings others have about the world"* (Creswell, 2009). Such adoption may bring risks such as bias a powerful participant is observed. The research questions have a more open-ended meaning for the reason that the researcher is keen in listening carefully what the participant believes or when analyses a specific situation.

In more detail, ontologically this research adopts a *Relativist* approach in which multiple, apprehend-able and sometimes conflicting social realities that are products of human intellects are assumed (Guba & Lincoln, 1994). The American Heritage Dictionary described relativism as *"the theory that value judgments, as of truth, beauty, or morality, have no universal validity but are valid only for the persons or groups holding them"*. Epistemologically, this research adopts a *Transactional/Subjectivist* approach in that the researcher 'sees' knowledge as created in interaction among him and the participants. Consequently, it appears that the conventional distinction between ontology and epistemology seems to disappear (Guba & Lincoln, 1994).

In summary, the aforementioned theories seek to inform the researcher of the interactions that exist within a BIM process environment, and that involves the stakeholders (practitioners and clients), the technology and the information that have to be managed in order to provide solutions regarding future-proofing issues for projects with high uncertainty.

5.5 *Selected Strategies of Inquiry*

As previously mentioned, various strategies were adopted for this research. The research design was identified in Section 5.3. Here, a more detailed description of the chosen design is presented. In Multiphase Design research, the overall objective of the programme is first established. Hence, the overall aim was to '*Develop a theory of positioning future-proofing as a phenomenon taking place in enterprise asset management and position BIM as an approach that communicates future-proofing'*.

The **Objective 1** was to determine the state of the art of FP and BIM in current research. Literature review was used for this objective and the findings were used to support the findings presented in Chapter 6 to Chapter 9.

For **Objective 2**, a Survey was used for data collection. The author initially participated in a parallel project. The author of that parallel project developed the instrument and collected the data. The study looked at how flexibility and standardisation emerge / integrate in a healthcare project. The author of this study analysed and interpreted the results of the Survey, discussed the findings with relative and contradicting literature and concluded on the findings. This work is presented in Chapter 6 and Appendix C.

For **Objective 3**, a Case study was used and the author observed an owner operator over a period of three months. Case study was chosen over Survey due to the fact that the author had access to various in-depth data and there was potential of investigating future-proofing in much more depth compared to conducting a Survey. For the same reason, another set of interviews was aborted because valuable conclusions could emerge by studying and triangulating various type of data. The outputs of this method are outlined in Chapter 7 and Appendix D.

For **Objective 4**, Semi-structured interviews were conducted with various stakeholders coming from all phases of a healthcare project. The interviews were structured and analysed using IPA analysis. Only the items that discuss future-proofing implementation processes were concerned at this stage. The output of this method are outlined in Chapter 8 and Appendix E.

For **Objective 5**, triangulation of the above interviews and case study data were used, in order to confirm and refine the findings of this final objective. The interview data were used as step one findings whereas the Case study data were used as step two findings, supplementary to the interview findings. This allowed for triangulation of the findings and being able to make generalisations with regards to the application of the findings across different research methods (Chapter 9).

5.6 *Selected Research Methods*

Research methods are instruments or tests or behavioural observation of a phenomenon. Choosing one method over another depends on the type of information that is to be collected. A summary of the research methods used is presented in **Error! Reference source not found.** distinguished into primary data and secondary data. The following sections elaborate more on each of the methods employed.

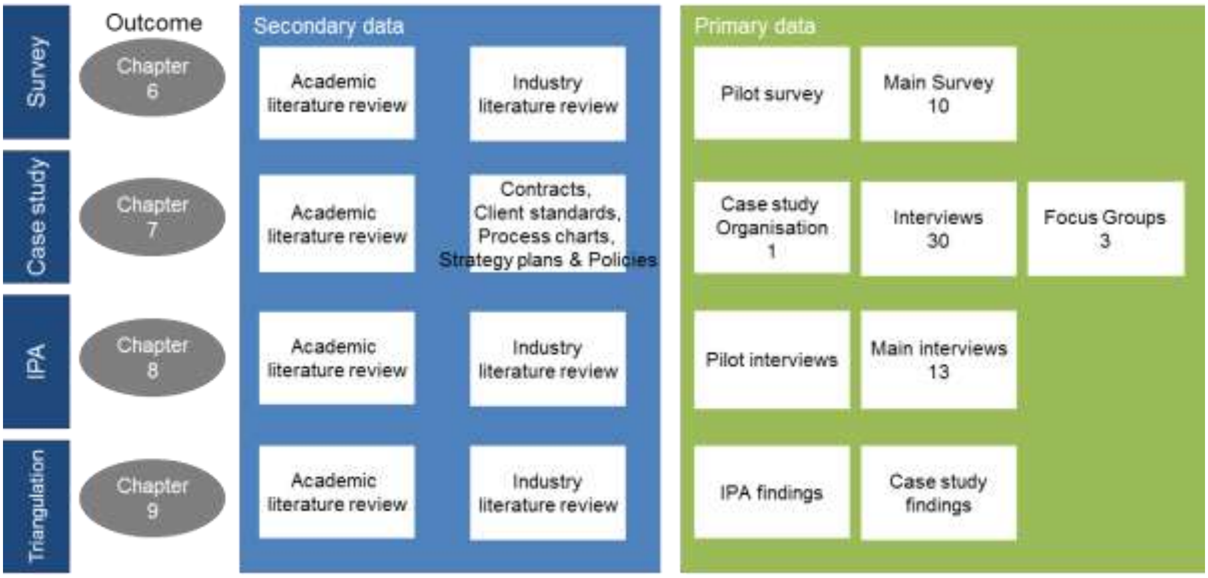


Figure 5-2: Research methods and data types used in this research

5.6.1 Literature Review Overview

Literature review in the fields of uncertainty in healthcare, future-proofing strategies and BIM were conducted first to gain an understanding on why it is important to make future-proof decisions for healthcare projects. Causes that lead to an inflexible system were identified in two areas, healthcare trends and healthcare policy. The role of BIM in construction was reviewed next. Literature related to future-proofing strategies was held next as it is considered a ground breaking method that addresses risks in projects with great uncertainty. The outcomes of this method are outlined in Chapter 2 to Chapter 4.

5.6.2 Survey Overview

The findings of this method are presented in Chapter 6. The population for the questionnaire survey included architectural firms in the UK and academics in the built environment. The pilot study was conducted first; it was uploaded to the members of a Web-based Group and a total of 48 responses were received. The pilot survey was revised and the main survey was conducted. The main study focused on soliciting the opinion of the top 100 UK Architectural firms based on the Building Magazine league table 2010. Out of 100 invitations, 10 (10%) responses were recorded.

The aim of the questionnaire survey was to explore the key factors that can enhance the designer's role when designing space for flexibility in healthcare facilities with the use of BIM. The survey was grouped into four sections: 1. background information of the respondents; 2. designing flexible healthcare spaces; 3. standardisation of healthcare space; and 4. flexible space design with BIM. The questionnaire survey targeted respondents such as architectural designers, healthcare planners and BIM users with healthcare experience in the AEC industry. A cross-sectional descriptive survey was designed as the preferred type of data collection as it enables a large set of opinions to be collected in a relatively short time.

Main Study - Background of the participants

Main sample: Top 100 UK architectural firms based on the Building Magazine, 2010.

To draw a representative sample, the quota sampling method was chosen [29]. The research interest is on UK Healthcare facilities. Therefore, only architectural firms that are based in the UK were considered. Next, the experts' opinion on design knowledge in terms of flexibility and design standardisation was measured. Companies with experience in the field of healthcare design were questioned. The top 100 UK architectural firms were ranked by the Building Magazine based on UK firms with the highest number of UK chartered architects. They were selected for their practical experience in the design of buildings in and outside the UK as described by Building Magazine. The architectural firms were contacted for the purposes of this research and were UK based whilst most of the architectural firms have international offices around the globe. Therefore, with both UK and international architectural working experience, the participation of such firms would provide robust practical data that this research can analyse and evaluate. All of the aforementioned firms were contacted; out of the 100, only 10 architectural firms responded (10%).

The years of healthcare and BIM experience for the main sample are presented in Figure 5-3. The level of experience in this sample is spread across different frames which gives a variety of experience in the two fields of interest. Based on the collected background information, inferential tests were applied to estimate the population's beliefs. The sample can be classified as a good sample for exploring the application of BIM in healthcare facility design, as healthcare design experience is satisfied and also the sample is experienced in the application of BIM. Over 50% of the sample has over 10 years of both healthcare and BIM experience. But it is noteworthy to understand that the sample is small (10 responses).

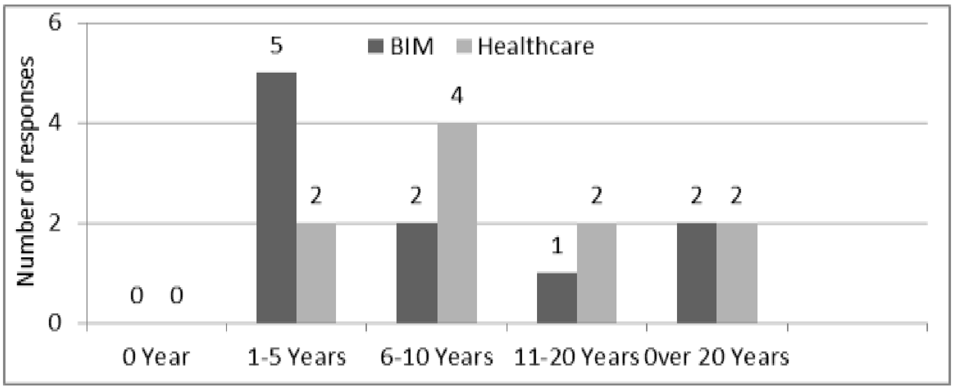


Figure 5-3: Years of BIM and Healthcare experience within main sample.

Data Collection and analysis

Both quantitative and qualitative data were collected, open ended and close ended questions were employed. Open ended questions were analysed by grouping responses into major categories. For example, the respondents were asked to identify spaces that commonly change. Their responses varied from multi bedroom to single bedroom etc. which eventually were grouped under a major category "bedroom". The questionnaire survey respondents were asked to put their answers in a ranking order. Eventually, the scores emerged by assigning points to each ranked answer. For instance, the respondents were asked to identify six spaces that change most frequently in a ranking order. The first given answer would get six points, the second gets five points and so on. Close ended questions were employed and respondents were asked to rate their agreement with statements using a five-point Likert scale. Respondents that opted for Highly Effective (HE) and Effective (E) were grouped together to estimate the proportion of "successes" of the question in context. The responses were then transformed to interval variables. Interval data *"are considerably more useful than ordinal data"* and *"to say that data are interval, we must be certain that equal intervals on the scale represent equal differences in the property being measured"* (Moore et al., 2005). As such, the difference between each five-level Likert item is the same. The sample proportion of successes was used to estimate the unknown population proportion. The analysis of the responses involved both descriptive and inferential methods. As a result, the number of successes and the number of failures are not at least 15, a simple practical adjustment first introduced by Edwin Bidwell Wilson in 1927 was employed, the *"plus four estimate".* In short, *"the adjustment is based on assuming that the sample* *contains four additional observations, two of which are successes and two of which are failures"* (Moore et al., 2005). The findings of this research strategy are outlined in Chapter 6 and in Appendix C whilst the survey template is presented in Appendix F.

5.6.3 Case Study Overview

The findings of this method are outlined in Chapter 7, Chapter 9 and in Appendix D. Following the survey, a case study research was conducted to investigate FP and BIM in more depth. Case study is a strategy where the researcher explores in depth a situation (event, activity, process). This in-depth investigation often means that there will be also a limited number of studies. According to Thomas (2011) case studies "*are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame—an object—within which the study is conducted and which the case illuminates and explicates".*

The study focused on understanding the dynamics which are present within an owner operator setting. The research was undertaken on behalf of the Maintenance and Operation division of the organisation under study focusing on the concept of future-proofing and the role of BIM for Operation and Maintenance (O&M). Following a holistic data collection process, both secondary data (desk study – existing documents, reports, standards, etc.) and primary data (stakeholder engagement, workshop attendance, etc.) were reviewed (see Figure 5-2). Through an emergent thematic analysis (Boyatzis, 1998) key areas for improvement were identified. Combined data collection methods took place over a three month period as they deemed necessary to provide a deeper understanding of the research problem. Taking into consideration other change management initiatives, the scope of this research was limited to the following:

- Review the current BIM Strategy (i.e. draft templates , documents, etc.) - desktop exercise;
- Analyse how the strategy relates to O&M: Create recommendations; identify 'low hanging fruits'; identify barriers and discuss how they can be addressed.

- Outline high level procurement commercials and contractual considerations with regards to future-proofing of assets across the enterprise.

More than 30 stakeholders were interviewed, spanning from both the procurement and the delivery side (Table 5-1). This helped identifying challenges for FP and BIM across the spectrum and create a holistic maturity of the subject under investigation. The researcher conducted interviews with various disciplines. This allowed to understand FP and BIM from many different points of view and helped understand the mechanisms and interrelationships at an enterprise level. In trying to capture this, the researcher engaged with commercial teams, geotechnics teams, software developer teams, asset management teams, procurement teams, GIS teams, system leads and asset management teams. Each of these meetings had different agendas and covered certain aspects of the topic under investigation. These were then analysis using Thematic Analysis. A sample of these notes is presented in Appendix H.

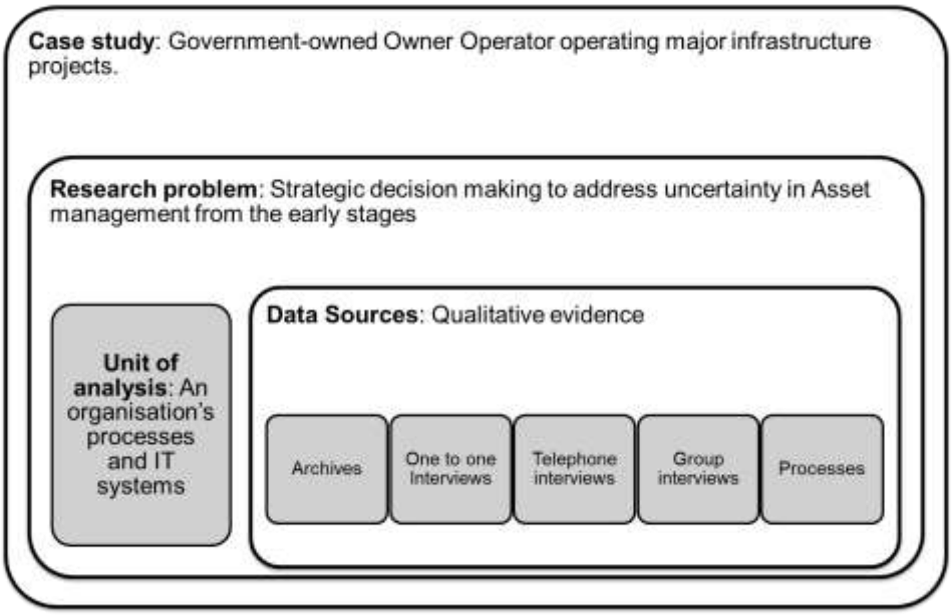


Figure 5-4: Case study overview

Table 5-1: Classification of Case study interviewees

Name	Title	Years of Experience	Delivery side	Notes	Meeting
Interviewee 1	BIM Lead-MP	0-5	Delivery	BIM lead client side	ongoing
Interviewee 2	BIM Sponsor	over 16	Procurement	Identify the overall BIM vision for organisation	ongoing
Interviewee 3	AMS Sponsor	11-15	Procurement	Identify the overall vision for NDD	17/04
Interviewee 4	AMS Senior User	11-15	Procurement	Link between AMS and BIM	ongoing
Interviewee 5	BIM Training Lead	6-10	Delivery	Leading on the BIM Training and Education front	ongoing
Interviewee 6	EIR Lead / COBie	over 16	Delivery	Leading on EIRs for the HA	ongoing
Interviewee 7	System developer	6-10	Delivery	Currently developing models / functionality to trial M1 Junction 19 handover into the IAM-IS system of Signage, Road Markings, Lighting Columns and Pavement. We are making good progress in preparation to reschedule the meeting we unfortunately had to cancel in January. We do have some feedback and also queries of the ADMM around Signage and Road Markings (see attached) which we could do with clarity on.	
Interviewee 8	Asset Manageme nt team	6-10	Delivery		03/02
Interviewee 9	Asset Manageme nt team	Over 16	Delivery	Quality assurance manager for EM Highways	02/04 & 13/05
Interviewee 10	AMS Delivery Lead	11-15	Procurement	Has knowledge in AMS, and O&M contracts. Has recently taken responsibility of COBie and Bentley academy.	26/03
Interviewee 11	Commercia l Manager	11-15	Procurement	Understand barriers for implementing BIM from a commercial perspective.	26/03
Interviewee 12	Project Sponsor	6-10	Procurement	Leads development of the company's Data Dictionary – setting out company's data standards.	26/03
Interviewee 13	Asset manageme	6-10	Delivery		26/03

	nt team				
Interviewee 14	BIM lead	6-10	Delivery	BIM lead from the supply side	31/03
Interviewee 15	AMS user	0-5	Delivery	Polishes related to pavements / geo-spatial aspects. Managing the Pavements system	13/04
Interviewee 16	AMS user	6-10	Delivery	Polishes related to pavements / geo-spatial aspects. Managing the Pavements system	13/04
Interviewee 17	AMS lead	11-15	Procurement	PM and Leading the AVIS team	10/04
Interviewee 19	AMS lead	11-15	Procurement	PM and Leading the AVIS team	14/04
Interviewee 20	Commercial manager	6-10	Procurement	Cost intelligence for MP – looks at cost and time	14/04
Interviewee 21	Commercial manager	11-15	Procurement	Commercial data analysis for MP and O&M – cost benchmarking	14/04
Interviewee 22	Procurement manager	6-10	Procurement	Did not attend	14/04
Interviewee 23	Procurement manager	6-10	Procurement	Company's group manager Midlands	14/04
Interviewee 24	Procurement manager	6-10	Procurement	Company's O&M procurement	14/04
Interviewee 25	AMS lead	11-15	Procurement	IT managing the Geotechnics system	14/04
Interviewee 26	AMS expert	0-5	Delivery	Polishes related to pavements / geo-spatial aspects. Assisting in managing the Pavements system	13/04
Interviewee 27	AMS expert	6-10	Delivery	AMS expert	13/05
Interviewee 28	AMS expert	6-10	Delivery	AMS expert	13/05
Interviewee 29	AMS expert	6-10	Delivery	AMS expert	13/05
Interviewee 30	AMS expert	6-10	Delivery	AMS expert	13/05
Interviewee 31	AMS expert	6-10	Delivery	AMS Systems Trainer	13/05

5.6.4 Interpretative Phenomenological Analysis Overview

IPA: what is it and why use it?

The study adopted interpretative phenomenological analysis (IPA) for recordings of perceptions. The aim of IPA *'is to explore in detail how participants make 10 sense of their personal and social world, and the main currency for an IPA study is the meanings particular experiences, events, states hold for participants'* (Smith, 2007). Both IPA and thematic analysis could have been used for data analysis, but IPA was chosen due to the fact that FP was studied as a phenomenon and the nature of the interview questions was closely related to that type of method. The theoretical lens used in analysing and interpreting the perspectives of the interviewees comes from the cognitive rather than the behaviourist paradigm that is broadly used in social sciences (Smith, 1996). The 'first-order' stage analysis took place once all the transcripts were completed (Larkin et al., 2006). A transcript was randomly picked and was read several times. First, initial themes were documented followed by emergent themes. The emergent themes were grouped together to provide 'grouped' themes, which in turn were reconstructed into high-level, mid-level and low-level themes according to the focus level they addressed (Larkin et al., 2006). The same process was followed with the rest of the transcripts, and the grouped themes that emerged were aligned back to the first set of high-, mid- and low-level themes that arose from the previous transcripts and wherever that was not possible new themes were added.

The 'first order' stage summarizes the participants' concerns and does not develop any further interpretative or conceptual level (Larkin et al., 2006). That 'interpretation' was done in the 'second-order' stage, where the investigator provided a critical and conceptual commentary upon the sense making perceptions of the participants (Smith & Osborn, 2007). In this second stage, engagement with existing theoretical constructs as well as interpretations about 'what it means' were used for the development of the framework (**Error! Reference source not found.**). More information about the conceptualization of the framework can be found in Sacks et al. (2010). At this stage, we quantified the items found under FP implementation and mapped them against the identified BIM capabilities, both of which emerged from the IPA interpretative part.

IPA analytic process

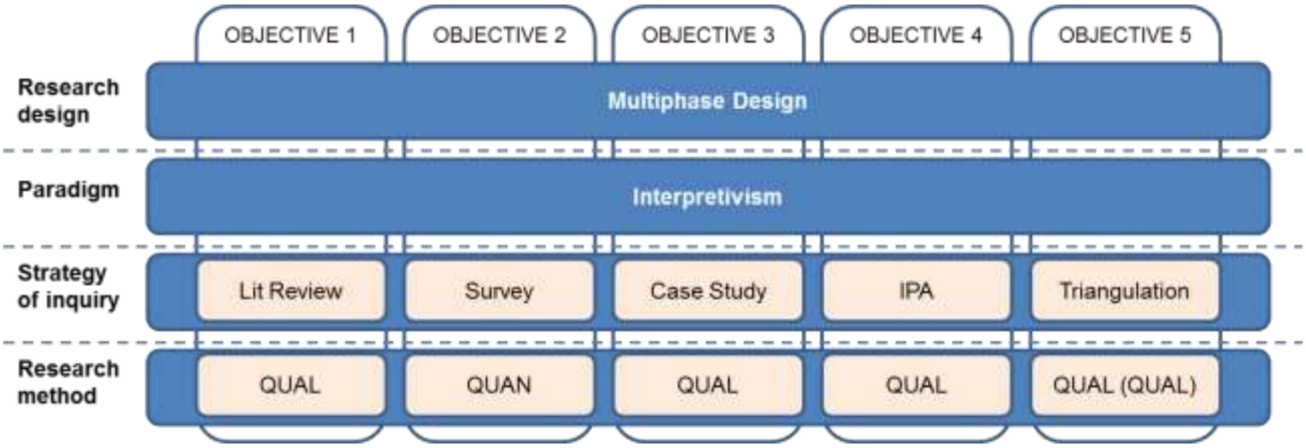
Firstly, we conducted a literature search about FP and selected sources which discuss it from a broad research spectrum. These were put together in task form and placed in a catalogue (pool of tasks). Then, we undertook interviews with health care experts and two themes emerged from the data, the first being FP specific and the second for BIM capabilities related to FP. The first theme offered a new set of tasks which in turn were added to the catalogue, together with the tasks derived from the literature. A summary table of the background of the interviewee health care experts is presented in Table 5-2. Table 3-1 outlines the tasks found in literature; the tasks identified by the interviewees are summarized in Table 8-2. The objectives shown in Table 3-1 come from Table 8-2 and were used to group tasks with similar scope. Each task was assigned a label according to the project phase in which it is found (i.e. P-I is a task found in [P]lanning phase etc., and the Roman numerals indicate the sequence of the objective within a particular phase). The BIM capabilities that were found are presented in Table 8-3. A combination of both sources of tasks (literature and interview data) was used and the outcome was the development of the objectives (Table 8-2) where they were further aligned to project phases. We developed an interaction matrix (**Error! Reference source not found.**) after analysing the interrelationships in the cross tabulations of the objectives (Table 8-2) and the BIM capabilities (Table 8-3). The table summarizes the interactions by counting each interaction as it occurs throughout the identified phases. All interactions emerged from the IPA analysis, and later, the results were quantified to ‘weight’ the interactions against the framework and thus giving a whole-life perspective of the two concepts. This interaction matrix aims to underpin theoretical relationships that exist between the two concepts. An attempt was made to support the emerging interactions with empirical evidence coming from experts, as presented in Table 8-4 to Table 8-9. The inclusion of verbatim extracts in these tables *“helps the reader to trace the analytic process, perhaps including more acknowledgment of analysts”* preconceptions and beliefs and reflexivity might increase transparency and enhance the account’s rhetorical power (Brocki & Wearden, 2006). The findings of this method are outlined in Chapter 8, Chapter 9 and in Appendix E.

Table 5-2: Classification of IPA interviewees

Code Name	Occupation	Healthcare Experience (years)	BIM Experience (years)	Delivery side	Duration (min)
I-1	Director of design	11-15	0-5	Delivery	79
I-2	Health Director	11-15	0-5	Procurement	63
I-3	BIM Manager	11-15	over 16	Delivery	47
I-4	Health Director	over 16	0-5	Delivery	63
I-5	BIM Manager	11-15	over 16	Delivery	63
I-6	Director of design	over 16	0-5	Delivery	44
I-7	General Manager IT	6-10	0-5	Procurement	78
I-8	Health Director	over 16	0-5	Delivery	65
I-9	Director of design	6-10	11-15	Delivery	53
I-10	Facilities Manager	0-5	6-10	Procurement	43
I-11	Clinical Program Manager	over 16	none	Procurement	61
I-12	Senior Project Manager	6-10	none	Procurement	64
I-13	Director of design	over 16	0-5	Delivery	58

5.7 *Chapter Summary*

In this chapter the discussion was structured by offering first a research framework that discussed research designs, paradigms, strategies and methods. A discussion of all the aforementioned elements of the research design were presented. A summary of the selected research perspectives adopted in this research is shown in Figure 5-5.



"Qual(Qual)" indicates that a first set of data were collected followed by a second set.
Figure 5-5: Summary of research perspectives

Chapter 6 Survey study[3]: flexibility and standardisation in healthcare design using BIM[4]

6.1 *Introduction*

In this chapter, key factors are explored that can enhance the designer`s role when designing space for flexibility with the focal use of building information modelling (BIM) and design standardisation. The objective of this preliminary study was to articulate the opinion of designers with healthcare and BIM experience on how satisfactory is design standardisation and BIM to accommodate flexible healthcare spaces. An exploratory study was conducted using a questionnaire survey[5]. The questionnaire was piloted to a Web-based Group (48 responses) and then it was distributed to the top 100 UK architectural firms (10 responses) based on the Building Magazine, (2010). Both descriptive and inferential statistics were used. The questionnaire survey included both open ended and close ended questions. The findings provide empirical insights about how design standardisation and flexibility can be applied with BIM.

6.2 *Discussion of findings from pilot sample*

Even though the pilot study was not the main study, some helpful conclusions were drawn regarding the instrument. The questionnaire survey was presented in two different formats; an online web link and MS Word document. Following the pilot study, this study further explored findings from architectural firms. Findings from the pilot study showed that some of the questions were left unanswered by the respondents. Therefore, during the main study some questions were omitted, while others were refined. Further information was provided in the "*more information*" section on the online questionnaire survey and the definitions of key issues in question such as flexibility, standardisation and BIM were presented in the beginning of each section of the questionnaire survey presented in MS Word format.

6.3 *Main study*

Main sample: Top 100 UK architectural firms based on the *Building Magazine*, 2010[6].

[3] Please refer to Section 5.6.2 for the detailed method used in this chapter
[4] The findings of this study have been published (please see Appendix C)
[5] Please refer to Appendix F for the Survey template
[6] Please refer to Section 5.6 – Survey Overview for the detailed method used in this study.

6.3.1 Designing flexible healthcare spaces

Regarding which spaces are most likely to be altered in healthcare facilities, the main sample ranked "*operating theatres*" as the first space that frequently needs to be changed, followed by "*bedrooms"* in second place and "*laboratories*" in third place. The same procedure for ranking the responses was used for the pilot study. The complete ranked spaces are presented in Figure 6-1. It is noteworthy to understand that the same three categories were identified by the Web-based group but in a slightly different order.

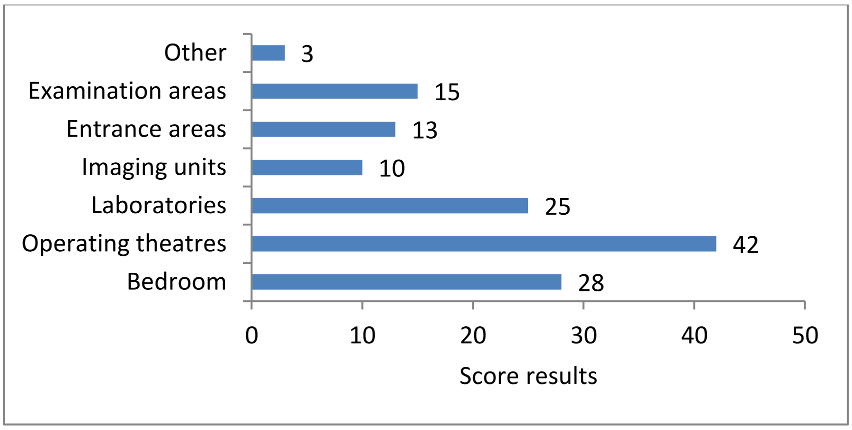


Figure 6-1: Spaces that frequently change in healthcare facilities.

The main sample ranked "*standards*" as the first most important consideration for designing flexible spaces, followed by "*services*" and "*cost*". Unlike the pilot sample, the main sample suggests "*cost*" as an important factor that needs to be considered in the design stage (Figure 6-2). The degree of effectiveness of six flexibility concepts is presented in Table 6-1. Three flexibility concepts "*modular design*", "*shell space"* and "*multipurpose foundations*" were rated equally HE/E and with 95% confidence that between 67.4% and 100% of the population would believe these three concepts are HE/E.

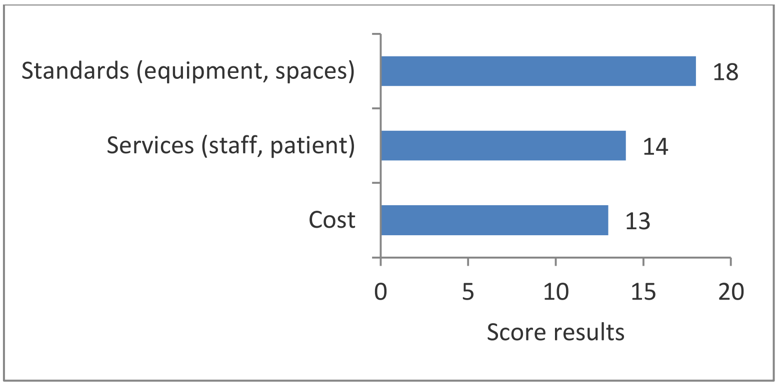


Figure 6-2: Top three important considerations for designing flexible spaces.

Table 6-1: Proportions, 95% confidence intervals and Spearman's rho on degree of effectiveness regarding specific flexibility concepts.

Main sample	**95% confidence interval results**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Modular design	1.000	.674	.857	-.467	.180
Shell space	1.000	.674	.857	-.082	.431
Flexible curtain walls	.951	.478	.714	-.140	-.629
Flexible furniture/equipment	.894	.392	.643	-.018	-.204
Multipurpose foundations	1.000	.674	.857	-.612	-.157
Flexible partitions/internal walls	1.000	.571	.786	.063	.179

Furthermore, correlation tests did not show any strong evidence that designers with experience in healthcare or in BIM tend to find more effective one concept of flexibility over the other (Table 6-2). Further correlation tests between the six flexibility concepts revealed that there are strong correlations among the concepts: "*flexible partition*"; and "*shell space*" ($r_s(10)=.913$, p.000); "*flexible partition*" and "*flexible furniture*" ($r_s(10)=-.922$, p=.000); and finally, "*flexible furniture*" and "*shell space*" with ($r_s(10)=-.866$, p=.001). A detailed list of the analysis results is shown in Table 6-2.

Furthermore, this study explored the opinion of architects about standardisation impeding flexible space opportunities by providing specification that could: produce rigid spaces/layout; produce interrelationship of spaces that are highly complex; or hinders modularity concept layout. There is a need to explore the application of standardisation in flexible healthcare spaces to achieve added value, cost effectiveness and cost efficiency (Price & Lu, 2013).

Table 6-2: Correlation tests for various flexibility concepts.

Test			Modular design	Shell space	Flexible curtain walls	Flexible furniture	Multi-purpose foundation	Flexible partition
Spearman's rho	Modular design	Correlation Coefficient	1	.764*	-0.375	-.661*	0.218	.697*
		Sig. (2-tailed)		0.01	0.286	0.037	0.545	0.025
		N	10	10	10	10	10	10
	Shell space	Correlation Coefficient	.764*	1	-.764*	-.866**	0.048	.913**
		Sig. (2-tailed)	0.01		0.01	0.001	0.896	0
		N	10	10	10	10	10	10
	Flexible curtain walls	Correlation Coefficient	-0.375	-.764*	1	.661*	0.327	-.697*
		Sig. (2-tailed)	0.286	0.01		0.037	0.356	0.025
		N	10	10	10	10	10	10
	Flexible furniture	Correlation Coefficient	-.661*	-.866**	.661*	1	0.082	-.922**
		Sig. (2-tailed)	0.037	0.001	0.037		0.821	0
		N	10	10	10	10	10	10
	Multipurpose foundation	Correlation Coefficient	0.218	0.048	0.327	0.082	1	-0.174
		Sig. (2-tailed)	0.545	0.896	0.356	0.821		0.631
		N	10	10	10	10	10	10
	Flexible partition	Correlation Coefficient	.697*	.913**	-.697*	-.922**	-0.174	1
		Sig. (2-tailed)	0.025	0	0.025	0	0.631	
		N	10	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

6.3.2 Standardisation of healthcare spaces

Most of the respondents agreed that standardisation could affect flexibility in all three categories *“some of the time”* (Figure 6-3). It was estimated with 95% confidence that between 64.0% and 100% of the population would believe that standardisation hinders modularity layout concept which is the strongest probability among the three statements. The statement that standardisation *“creates rigid spaces/layout”* was ranked second (with 95% confidence between 47.8% and 95.1%) and “produces interrelationships of spaces that are highly complex” was ranked third with significantly low probability (with 95% confidence between 31.2% and 83.1%).

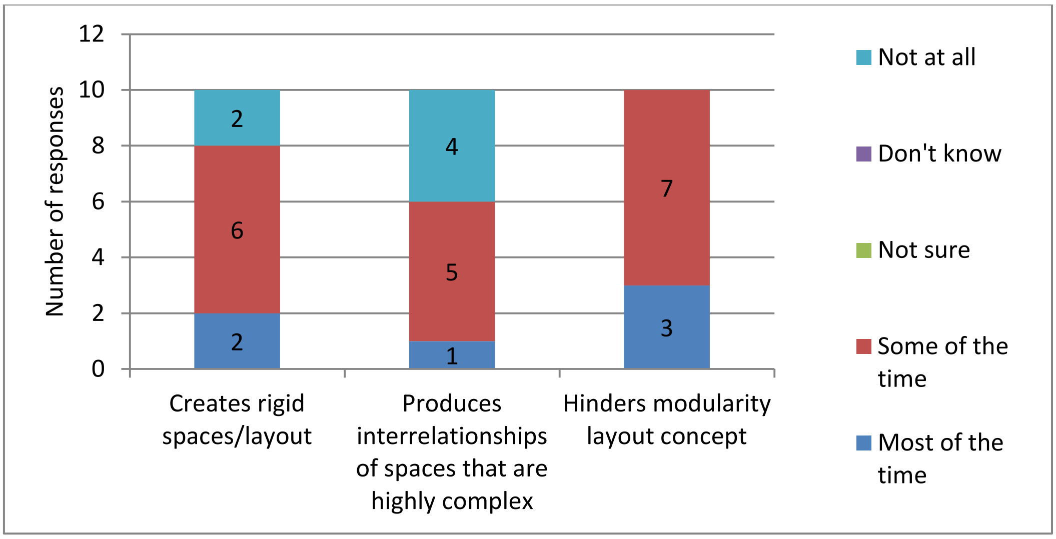


Figure 6-3: Opinion of respondents on standardisation impeding flexible space opportunities.

The responses for each of the three statements were tested against the years of BIM experience as well as the years of healthcare experience the respondents had. There is no strong evidence to suggest that there is a linear correlation that designers with experience in healthcare or in BIM tend to agree that standardisation impedes flexibility in any of the three statements. The 95% confidence intervals for the population and the spearman's coefficient are presented in Table 6-3.

Table 6-3: Proportions, 95% confidence intervals and Spearman's rho on standardisation impeding flexible space opportunities.

Main sample	**95% confidence interval results**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Creates rigid spaces/layout	.951	.478	.714	.384	.000
Produces interrelationships of spaces that are highly complex	.831	.312	.571	.119	.156
Hinders modularity layout concept	1.000	.640	.857	.204	-.157

6.3.3 Flexible space design with BIM

The results suggest that BIM is effective for both short-term and long-term analysis and evaluation of flexible healthcare spaces with 95% confidence that between 57.1% and 100% of the respondents would believe BIM is HE/E on a short-term basis. While 67.4% and 100% of the respondents would believe BIM is effective on long-term basis. Spearman's tests revealed that there is strong degreasing linear correlation ($r_s(10)=-.633$, $p=.049$) for the respondents with high BIM experience that believed BIM is effective to inform decisions on short-term basis.

Finally, no evidence suggests that designers with more experience in healthcare or find BIM more effective for analysing and evaluating flexible spaces on long-term basis. Detailed results are presented in Table 6-4.

Table 6-4: Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing and evaluating flexible healthcare spaces to inform decisions on short-term and long-term basis.

Main sample	**95% confidence intervals**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis Sig. (2-tailed)	1.000	0.571	0.786	-0.633* .049	0.304
Long-term basis	1.000	.674	.857	-.326	.157

Next, the respondents were asked to rate the effectiveness of using what if scenarios in the design of flexible healthcare spaces on the same two decision foundations: short-term and long-term basis. It was estimated with 95% confidence, that between 23.8% and 76.2% of the population would find effective the use of what if scenarios on a short-term basis. On the other hand, between 67.4% and 100% of the population would find what if scenarios effective on a long-term basis. Finally, the Spearman's tests did not show any significant level of linear correlation between the respondents rating of the effectiveness of what if scenarios and the years of experience in healthcare or BIM (Table 6-5).

Table 6-5: Proportions, 95% confidence intervals and Spearman's rho on the effectiveness of using what if scenarios with BIM in the design of flexible healthcare spaces.

Main sample	**95% confidence intervals**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis	.762	.238	.500	-.148	.204
Long-term basis	1.000	.674	.857	.490	.039

The respondents were then asked to agree or disagree that BIM tools hinder design innovation and creativity (Table 6-6). The results showed that the population would believe BIM tools hinder innovation and creativity "*all the time*" (57.1%-100% with 95% confidence). Spearman's tests revealed there is strong degreasing correlation ($r_s(10)=-.638$, $p=.047$) for the respondents who Strongly agree/agree that BIM tools hinder design innovation and creativity *"all the time"* with experience in healthcare design.

Table 6-6: Proportions, 95% confidence intervals and Spearman's rho on the degree of dis (agreement) that BIM tools hinder design innovation and creativity.

Main sample	**95% confidence intervals**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
all the time	1.000	.571	.786	.133	-.638*
Sig. (2-tailed)					.047

*Correlation is significant at the 0.05 level (2-tailed).

In the last question, the respondents were asked to indicate their opinion about the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility spaces. The given strategies were *"expanding"*; *"contracting"*; *"relocating"*; and *"adapting"*. The responses vary and this can be seen on the relative low proportions in Table 6-7. The analysis showed that the population would believe that BIM is likely to benefit more projects that focus on "*expanding*" and "*contracting*" (23.8%-76.2% with 95% confidence) over projects that focus on "*relocating*" (0%-44.8% with 95% confidence) and "*adapting*" (1.6%-58.4% with 95% confidence). Regarding the Spearman's correlation tests, there is no significant linear correlation concerning the applied flexibility strategies and the years of experience the respondents have in BIM or in healthcare.

Table 6-7: Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing, evaluating and modelling flexible healthcare facility space strategies.

Main sample	**95% confidence intervals**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Expanding	0.762	0.238	0.500	-0.148	0.204
Contracting	0.762	0.238	0.500	0.004	-0.207
Relocating	0.448	0.000	0.200	0.118	0.284
Adapting	0.584	0.016	0.300	-0.131	-0.596

6.3.4 Discussion of main study findings

The study's key findings regarding the three major fields of interest are presented below.

Designing flexible spaces: this research can conclude that the three types of changes identified by Slaughter (2001): spatial, flow; and structural are features of a rapid changing space, but if one asks what spaces are these in a healthcare facility, what would be the answer? The main sample identified *"bedrooms"*, *"operating theatres"* and *"laboratories"* as the top three categories of spaces that are frequently subjected to change. They further identified *"standards"* as the most important consideration for design flexible spaces. Under standardisation hinders the knowledge of equipment specification and the type of room to be applied in a healthcare facility and so on. Another concept that was ranked as important was *"services"* which calls for identifying practices and operations required by facility users (staff and patients) at early design stages during the project's lifecycle; information regarding standards and services is included in ADB. The functional services required define the type of MEP services desirable for the functional space design. Lastly, the main sample identified *"cost"* as an important consideration for the early design stage of a project. One effective method in construction management centred on cost is Target value design. The analysis also highlighted that designers find open building principles (shell space) highly effective; they also found adaptability strategies such as *"flexible partitions"* and *"flexible furniture"* highly effective.

Standardisation of healthcare spaces: the respondents' agreed that standardisation is not the panacea for designing flexible healthcare spaces and this is shown in **Error! Reference source not found.** where the 95% confidence intervals showed a very strong probability with 64.0%-100% of the population were of the view that standardisation "*hinders modularity layout concept*". Contrary to the above, "*modular design*" was ranked first among other flexibility concepts in Table 6-1. Modular design supports standardised units or standardised dimensions to support construction (Waskett, 2001). Modular design or prefabrication is described as an advanced construction technology that allows a building to be flexible at a short notice while keeping cost as a primary concern. In Addenbrooke's Hospital, the use of such methods was applied and significant time efficiency was noted (de Neufville et al., 2008). As a design principle, the respondents agreed that *"modular design"* is a preferable choice for accommodating flexibility.

Flexible space design with BIM: the respondents were of the view that the use of BIM is effective in the design of flexible spaces on both long-term and short-term plans. Within the two bases of application, the respondents were of the opinion that BIM is exploited on a higher rate with regards to *"long-term basis"* concerning the design of healthcare facilities (see Table 6-4 and Table 6-5). Regarding the use of a flexibility strategy with BIM, the results showed that strategies such as "*contracting*" and "*expanding*" are more beneficial than strategies such as "*adapting*" or "*relocating*". Conversely, the respondents identified adaptability and open building as the most effective strategies for approaching flexible space design. Comparing these findings; it can be concluded that BIM as a process and a technology should provide improved applications to meet users` demand in regards to the application of adaptability. Further correlations tests (Table 6-2) revealed that there is strong correlation between two flexibility strategies: *open building* and *adaptability*, since respondents who chose *"shell space"* also chose *"flexible furniture"* or *"flexible partition".*

6.4 *Chapter Summary*

The study was essentially exploratory in nature, with a small but experienced sample. Hence, the findings should be considered with caution. It suggests that embedding flexibility can be enhanced with BIM by supporting the generation of different design options and scheduling design tasks with different information attached. The results also showed that strategies such as "*adapting" "contracting"* and *"expanding"* are more beneficial than other flexible strategies.

Regarding standardisation and flexibility, the results showed that although it was noted that standardisation may impede flexible solutions, it is indeed applied and in construction projects that require flexibility through prefabrication and advanced manufacturing methods. The chosen research approach measures, records and reports the perceptions and worldviews of the respondents. Therefore, the research findings are based on how reality is formed by the participants and their experiences. With that in mind, the information identified was used to draw some noteworthy findings that provide detailed information on embedding flexibility in healthcare buildings.

Chapter 7 Case study[7]: future-proofing governance and BIM for owner operators in the UK[8]

7.1 *Introduction*

Owner operators are managing and maintaining their infrastructure assets. In addition, depending on the national economic activity, they are being reactive or proactive in their response against uncertainty. Findings from this study showed that improvements can be achieved if the concept of future-proofing (FP) of assets – as a structured approach against uncertainty – becomes more explicitly defined. FP is the holistic process of taking security measures against uncertainty and being proactive throughout the organisation and its assets. In combination with information management, it ensures that asset management (AM) strategies will become responsive to a number of future changes in requirements. In this context, it is asserted that both FP and Building Information Modelling (BIM) suffer from a dearth of identification in the context of enterprise AM. Through a case study, this chapter presents an approach that helps clients to future-proof AM at a strategic level. Furthermore, governance agendas for FP and BIM capabilities for future-proof information have been identified that owner operators and the supply chain can find useful.

7.2 *Background of the organisation under study*

This chapter reports on the research undertaken on behalf of a major infrastructure operator focusing on BIM for operation and enterprise asset management. The investigated Owner Operator is a government owned company which manages major linear infrastructure assets. The Organisation operates in the UK and has more than 3500 employees. The organisation under study is a major infrastructure owner operator with asset all over the UK. It operates information services, liaises with government agencies and provides staff to deal with incidents on the assets it manages. The organisation's operations are split into seven areas across the regions of England. These areas are subdivided into more than 13 operational areas. These areas are managed and maintained by an area team and an asset

[7] Please refer to Section 5.6.3 for a thorough review of the method used in this chapter
[8] The findings if this study have been published (please see Appendix D)

management contractor. In addition, there are a number of sections of road that are managed under long lease contracts separately from the area teams.

Within the organisation there are two key categories of investment:

- Those delivered through Major Projects (Major Project schemes)
- Those delivered by the asset management division as part of their ongoing operations and maintenance process.

Major Projects (MP) schemes are generally focussed on delivering large investment programmes for new sections of carriageway, or major expansions of existing assets. These schemes are typically implemented from phases Brief to Handover.

The Asset Management division is responsible within the company's portfolio management for owning and maintaining the organisation's asset portfolio. Asset management schemes are delivered through a variety of mechanisms, who essentially maintain both the assets and the asset information on behalf of the organisation. The mechanism of delivery used within the operation type contracts is generally driven by an investment-based categorisation of the work involved, using from small schemes through to those of a similar scale to a small-type major project:

- Scheme 1: £0-£30k
- Scheme 2: £30k-£250k
- Scheme 3: £250k-£1M
- Scheme 4: £1M-£5M

Asset Management teams are responsible within the Owner Operator's portfolio management agendas for owning and maintaining their asset portfolio. Within an Owner Operator there are in general two key categories of investment:

- those delivered through Capital Projects; and
- those delivered by the Operation and Maintenance teams through their ongoing Operations and Maintenance (O&M) processes.

Capital Projects schemes are generally focussed on delivering large investment programmes for new sections of infrastructure, driven by need for capacity enhancement (UK Trade & Investment, 2014). These schemes are typically implemented from phases Inception to Handover. On the other hand, Operations and Maintenance schemes are delivered through a variety of mechanisms, such as a variety of contracts and also by a variety of stakeholders. These stakeholders essentially maintain both the assets and the asset information on behalf of the owner operator. The mechanism of delivery used within the vast variety of contracts is generally driven by an investment-based categorisation of the work involved, varying from small schemes through to those of a similar scale to a small capital project. A number of potential areas for improvement have been identified. These improvements are presented in detail in this chapter.

The asset management division interfaces with respect to communication regarding and receipt of data are grouped into internal interfaces and external interfaces.

Internal Interfaces

The asset information team is a supporting function within the asset management division and hold overall responsibility for the organisation's asset inventory data. The division also interfaces with the MP delivery team, which deliver new build and major renewals / improvement projects through a variety of contractual mechanisms, such as collaborative frameworks as well as traditionally tendered work (e.g. DBB).

External Interfaces

As identified above, the division needs to interface with the MP Supply Chain, and also with its portfolio of O&M contract suppliers. However, in practice, much of the interface with MP (particularly in terms of data and asset management information) is carried out by the O&M contracts on behalf of the division. Similarly, in terms of 3rd party works, much of the engagement and interface is carried out by the O&M contracts on behalf of the division. This generally takes the form of the O&M contracts taking the handover information from the project, processing it and adding the relevant entries into the relevant asset management system (AMS). Some of the systems provided to the regional asset management teams so as to collect and maintain asset information relevant to the contract agreed. There currently are more than 16 systems that maintain legacy data but the organisation is developing a holistic AMS which will host most of the data hosted currently in those legacy systems.

In brief, the methodology and process adopted includes:

- engage with circa 30 stakeholders to understand their requirements regarding BIM and future-proofing asset management within the organisation and its supply chain;
- review the outcomes of those meetings; and
- identify key themes for BIM and future-proofing the organisation's asset management strategy.

Following a holistic data collection process, both secondary data (desk study – reviewing of existing documents, reports, standards, etc.) and primary data (stakeholder engagement, workshops, face to face interviews etc.) were reviewed (please also see 5.3.4.e for the complete description of the case study methodology). Through an emergent thematic analysis key areas for improvement were identified and a comprehensive list of recommendations was produced.

Lifecycle Information Management for the Owner Operator

For the organisation under study where little or no pre-existing data were available regarding an asset; it affords the opportunity to create and maintain a repository of information related to the asset's design and construction life. This information can be called upon during its operation, maintenance and use. Further, as O&M teams maintain and update graphical and non-graphical data; its value increases further, eliminating investigative work, allowing monitoring of warranty or durability criteria and generally improving the understanding of how the asset operates (or contributes to the operation of a facility).

In order to maximise the potential for collaboration and minimise potential wastage or information loss during the development of these Project Information Models (PIMs), the government has mandated relatively formalised and robust standards around BIM. The standards not only cover the structure of these PIMs, but also the processes to be used to develop and deliver them. It is a key element of this 'future-proofed lifecycle' model, that asset data is collected during the design, construction and commissioning phase to ensure that the 'as-built' PIM can be used as the foundation of operations and maintenance schedules (as-maintained). Furthermore, many of the more preliminary project stages through to commissioning will have key information inputs into the decision making process, and this data should also be retained within the PIM for legislative, consultative and maintenance use.

Moving past the 'first cycle' of the Information management process, the aspiration is that both the graphical and non-graphical data will form a key part of future BIM projects as the definitive set of existing spatial and key requirement constraints. Thus they will be used to help inform design and construction options and solutions. In order for this to be possible it is key that data is maintained, and therefore the natural repository for the data is within the Asset Management Systems (AMS) that the Owner Operators will use for their day to day operations. In the instance that the asset data has been altered, renewed or removed then this should be recorded and the updated information should be re-saved back to the 'home' database.

7.3 *Future-proofing governance considerations per agenda*

To showcase how a mutation cycle (discussed below) can be initiated, the following emergent themes have been identified and are presented into two main categories, namely FP governance considerations across three agendas and the capabilities BIM can offer around FP solutions. For successful AM and delivery of future-proofed assets, a formal FP process needs to be formalised. This process, depending on the agenda, varies in terms of what needs to be considered. The three high-level identified agendas are outlined here.

Government agenda includes actions for both FP and BIM and works as a controlling and supporting mechanism that ensures clients and the supply chain are working together for the delivery of future-proof assets.

Strategic management agenda includes decisions the client are taking with the support of the supply chain. These decisions are about obtaining assets with the best possible change-readiness incorporated throughout their lifespan.

Information management agenda includes processes and support from technology the supply chain needs to adopt in order to deliver the goals and aspirations set by their clients.

7.3.1 Government agenda

With regard to FP, there are two actions that could to be pushed further by the government.

Future-proofing actions: These are actions that will allow the government to monitor and support the owner operators obtain futureproof assets. For this to be done, there is a need to foster organisations into creating mechanisms and processes that will support and enhance FP. The following actions have been identified.

- Include contractual requirements that will further support the delivery of FP solutions.
- Establish an FP ranking system where each project/asset can be mapped against its FP capability on a national level.
- Support organisations into developing their FP key performance indicators (KPIs).

BIM actions: The second action in this agenda should consider how to use BIM processes with regard to FP. The following actions have been identified

- Many clients are now focusing on implementing their BIM standards and are starting to understand what BIM and its outputs could mean to them. There needs to be a central control by a government body that will ensure that these standards are sharing common principles. This can be proven to be highly effective for all asset owners regardless of sector as quality assurance standards and high-quality BIM services across all markets, sectors and projects will be ensured.

- Case studies that showcase evidence, lessons learnt and KPIs achieved from using BIM best practices for FP asset management.

- Guidance and support on how to approach BIM to ensure FP of information and what aspects of BIM can better support FP solutions and processes.

7.3.2 Strategic management agenda

On the delivery side, the clients need to work with their supply partners to agree over a common strategy on how change-ready assets should be delivered. The following decisions will support this goal.

Strategic decisions: These are decisions that ensure that the clients' goals are clearly communicated to their suppliers. From the suppliers' side, there is a need to ensure that the clients' requirements are addressed. The following will support strategic decisions around FP.

- FP objectives are ingrained into a plan of works flow.

- The clients do not focus solely on capital cost but support the supply chain to deliver projects where design life is priority.

- The change-readiness framework (discussed below) is considered at the early stages of the project.

- Change of mind-set that considers ‘payment by results’ the only justifiable driver when discussions around future changes/upgrading emerge. Clients are starting to realise that upgrading of services/upskilling of resources is as important as the increase of customers' service provision.

- The clients should incentivise their suppliers to deliver projects where whole-life cost is reduced as opposed to solutions that are targeted for lower capital cost.

- Clear clarification of FP goals. For instance the clients should have clear understanding of where they want to have FP feed within their assets. It is uneconomical to have as a requirement an asset that should be 100% future-proofed, as this is unrealistic and can also be an expensive solution.

Cooperative decisions: These types of decisions are supportive of the strategic decisions described earlier. These decisions highlight the need for a change in behaviour during decision-making. For example the delivery teams can adopt a more 'considerate' behaviour regarding the asset management teams. The following can support this.

- During design and construction delivery, if the teams identify that there are areas within the asset that could be considered to be 'problematic' in the near future, they should highlight this and try to find solutions that will overcome the issue rather than leaving it to be dealt by someone in the future ng can support this.
- Decisions should be given by all stakeholders – that is, the teams that will eventually manage the assets should be invited at the early stages and share their knowledge. As this may raise conflicting interests, there is also a necessity that decisions should be based on pre-agreed weighted criteria.
- The supply chain should bring lessons learnt from other projects regarding the application of best practice in FP.

7.3.3 Information management agenda

Information management has now become an integral part of project delivery. BIM consists of processes around information management; furthermore, these are aligned with traditional project management processes. Furthermore, information management consists of processes that heavily rely on the support of technology.

Implementation processes: To efficiently deliver data that can be used for FP, the following should be considered.

- The presence of Employer's Information Requirements (EIRs) as a contractual document that outlines information contractual deliverables is becoming more and more present in the contractual agreements for new projects. As part of the EIRs, there is a need for asset information needs to be clearly defined to ensure that asset data will be produced for efficient AM.

- During the maintenance cycle, EIRs may not be relevant, as in most cases design is not required. Therefore, only Asset Information Requirements need to be developed. These requirements identify which assets are maintained and are updated in the database.

- As a response to the EIRs, the BIM Execution Plans (BEPs) need to ensure that the supply chain processes will deliver asset requirements that can be retrieved and reused

- Following the BEPs, the project information models (PIMs) will include data that can be used by the AM teams to inform their operational decisions after handover by non-design experts.

Technology support: To carry out the preceding processes, it is important to ensure that technology supports and not hinders these capabilities. The following are the minimum requirements.

- Interoperability should be ensured across BIM tools (BIM authoring tools, common data environment) and AM systems, software-agnostic solutions such COBie, .csv and IFC files could be used.

- By recognising that data will be maintained in an electronic format throughout an asset's lifespan, there is a need to ensure that each piece of data will have a unique ID so that it will be protected from being lost or overwritten.

- AM systems have the functionalities to receive and capture data that can be used for life cycle decisions.

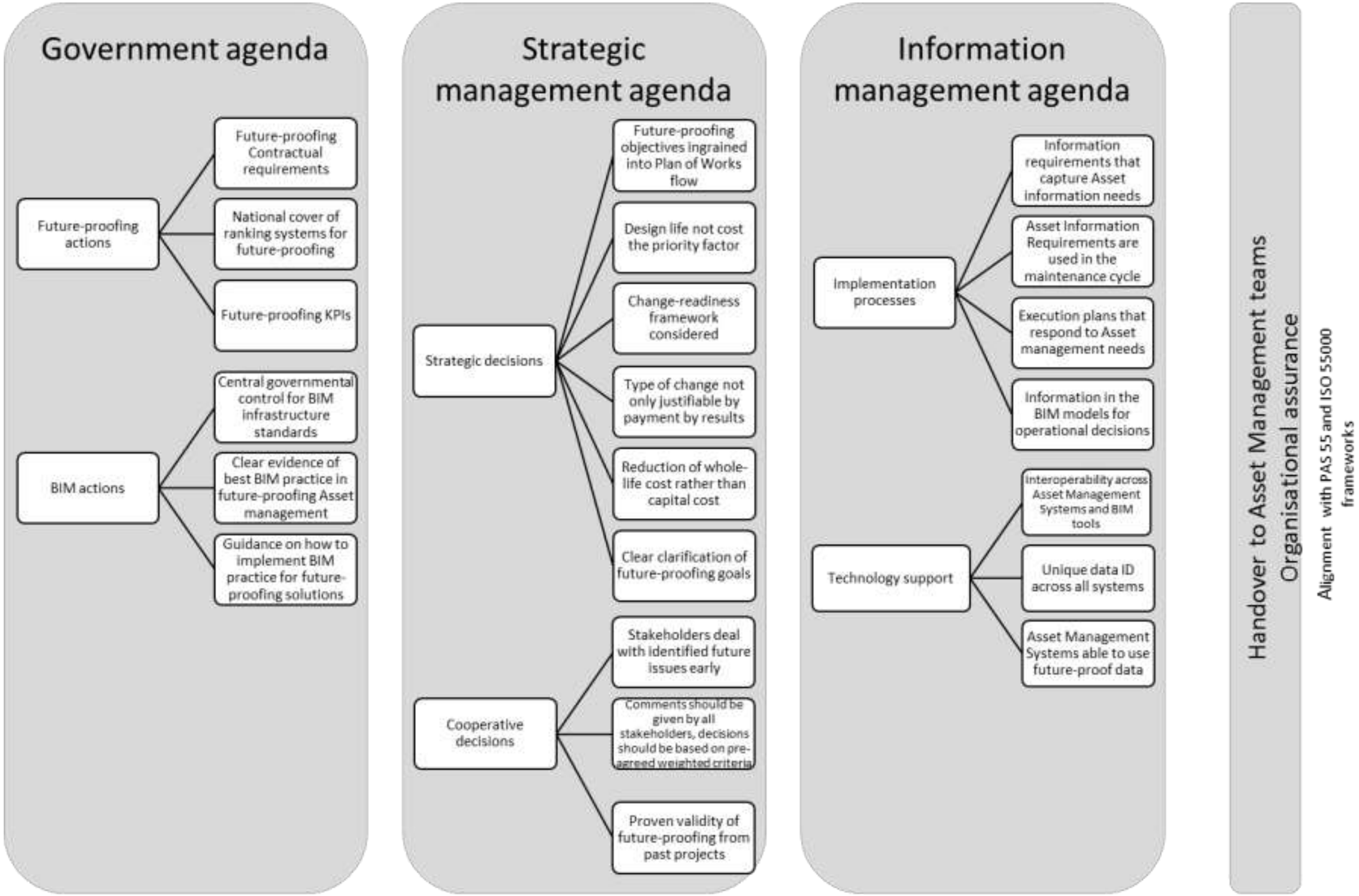


Figure 7 4: Future-proofing considerations / responsibilities per agenda

7.4 *Change-readiness framework*

The following change-readiness framework provides clarifications regarding the range of ‘what’ could change as well as an indication of ‘when’ this could happen (Figure 7-1). Slaughter (2001) discussed three types of changes that can occur within an asset; these changes are regarding the asset’s flow, function and capacity.

Flow: The first type of change involves changes in:

- environmental flows – for example a change may be required to occur due to a climatic change or physical environmental conditions within the asset; and
- flow of people/things that may occur from an organisational change decision

Function: For infrastructure projects, such changes may occur as result of:

- reusing existing functions – upgrading an existing space for better performance;
- creating new functions – creating an existing space for additional functions; and
- changing for different functions – altering the space for different functions to apply.

Capacity: the third type of change. It is related to the structural transformation of the asset to meet specific performance requirements. Changes in capacity may occur from changes regarding the asset’s ‘volume’ and/or ‘loads’. Essentially, these changes are focusing on ‘size’. Transformation is more rigid compared to the first two categories; these type of alterations are also more expensive.

De Neufville et al. (2008) categorised three types of applications as they emerge into an asset life cycle: operational, tactical and strategic applications. The asset will perform as it was originally designed, but, in addition, there can be an additional ability within the asset that can be described as a switch. In effect, the owner can switch this ability on and off depending on the internal and external factors that emerge. Each type of application can be considered as moving from one level to the next while directing the asset to adapt to changing needs dynamically.

- *Operational* or short-term applications are the lightest form of change and the easiest, as these can be applied on a daily or weekly basis. This change finds application in light systems. The application can be cost-effective while endorsing a rapid ongoing change in the short term.

- *Tactical* or mid-term applications reflect a more permanent response in the change scale and thus require significant capital to be reverted. In order for this application to be effective, the initial capital cost of the asset could be higher (10–20%). The application is used to address medium-term uncertainty, and to become effective. It could take a few weeks of implementation.

- *Strategic* or long-term applications are strategies that owner operators could apply in considering the end life of the asset. The effort of deploying this option is to increase significantly the life expectancy of the asset. Owners would expect this application to become effective after years of handover of the asset.

Moreover, cost is increasing from one application to the next. The change-readiness framework is used for informing an effective FP approach. An exercise of identifying options across this graph reflecting the asset's lifespan can inform the 'lifespan asset optioneering' exercise in the mutation cycle as discussed in the following sections.

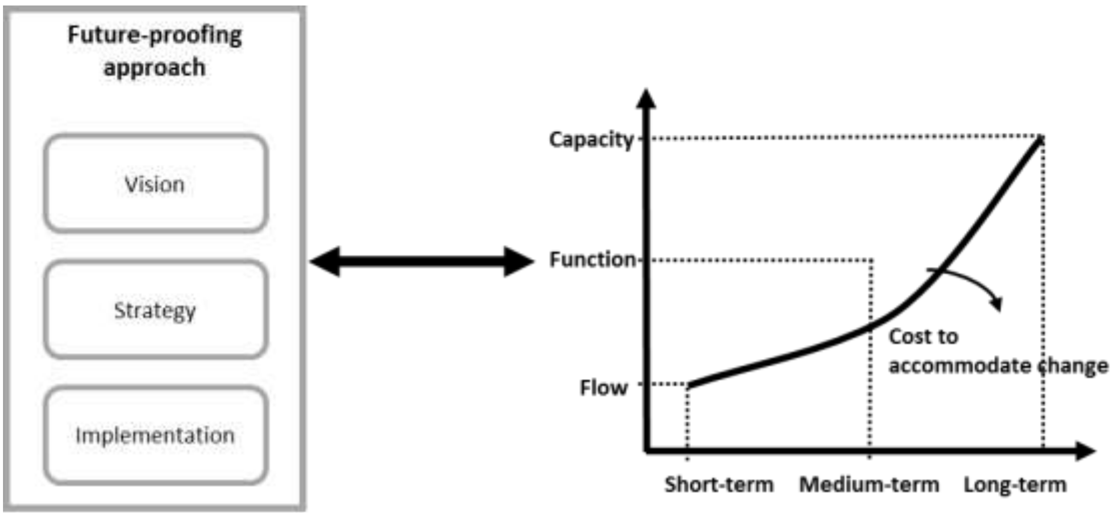


Figure 7-1: Change-readiness framework aligned with the FP approach

7.5 *BIM capabilities that support future-proofing*

As discussed in the previous sections, there is real opportunity for both the clients and the supply partners to benefit from the use of BIM. This metacritique serves as an identification of the qualitative competences that exist in a BIM process environment.

The following supportive capabilities have emerged, and these are summarised in Figure 7-2.

- *Flexible data*: Flexibility in this instance means that the data can be used by multiple teams across the project and throughout the asset's lifespan for multiple purposes. To ensure data flexibility, there needs to be a standard procedure for information exchange and systems interoperability. All of these challenges are trying to be addressed within a BIM process.

- *Optioneering capabilities*: Optioneering studies are becoming more easily implemented within a BIM process framework. Information has become easily accessible, and this is further supported by technology advancements. BIM not only offers the possibility of running many 'what-if' scenarios to choose the best possible solution based on the clients' requirements but it can also be used for evaluating possibilities regarding the scenarios an asset can accommodate post-handover (life cycle asset optioneering).

- *Project evaluation*: BIM is also becoming a quality assurance process for evaluating models and validating data input. In terms of FP, BIM can be used for quantifying how futureproof an asset can be, identifying resilient-sensitive areas and informing decision-making.

- *Standardised object catalogues*: Just like in the automotive industry, it is now possible to have libraries of components that can be reused from project to project, saving time and resources. These components and their properties can in addition be backed up with evidence – that is, performance, durability, maintenance conditions and so on – to better support FP decisions.

- *Whole-life costing*: Essentially this is the main purpose of moving towards BIM process delivery. The PAS 1192-2 (BSI, 2013) and PAS 1192-3 (BSI, 2014) specifications outline how a capital expenditure model will be used to support operational expenditure purposes. With BIM it is now possible to have whole-life cost models in place and evaluate future scenarios about the asset in question. The design models can be linked to cost databases that effectively investigate the best solutions from a pool of solutions that are ingrained within the design model itself.

- *Whole-life communication*: Communication of requirements, rich-based complex databases and early data that can be useful for the AM teams is only one example that makes communication the strongest capability of BIM. Communication is the key to the effective delivery of change-ready assets, and volumetric design, software-agnostic exchange packages (i.e. COBie) and visualisations are some of the examples of this capability.

Figure 7-2: BIM support capabilities for FP development

7.6 *Lifecycle asset optioneering and mutation cycle*

The previous sections captured the governance considerations for life cycle asset optioneering as well as the qualities offered from the adoption of BIM. In this section, a mechanism is proposed that takes into effect the governance considerations (3 agendas) and BIM capabilities. Present approaches involve the client procuring for a new development suggesting that the supply teams need to provide a number of proposals (approximately three) and then, after evaluation of the three propositions, the team will produce a feasibility study based on a single preferred option (SPO). FP takes a different stance and suggests that the clients should steer their approaches on a different direction. By considering the above, it is then possible to re-engineer the procurement process and stimulate alternative design approaches that will protect the lifespan of the asset. Implying a switch is incorporated into the asset; it is then possible that during its lifespan the asset will be able to readjust itself into the business needs the organisation is required to respond. The asset lifespan in essence becomes the mutation cycle identified in Figure 7-4, and instead of an SPO, the clients acquire a current preferred option (CPO) solution. A CPO identified in the initial stages ensures that the design will have the insurance embedded into the asset that will allow it to address change at a set period in time.

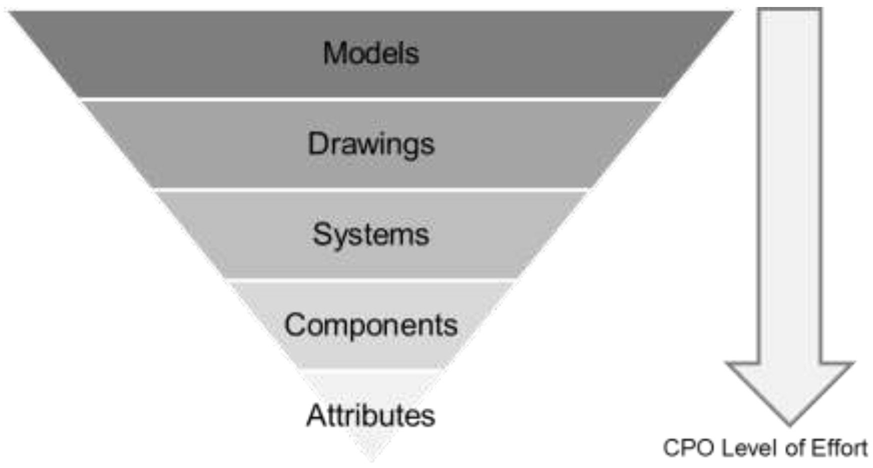


Figure 7-3: Current preferred option levels of effort

Post-handover the asset lifespan starts, and the asset will eventually be challenged by many internal (new policies, change of services etc.) and external factors (political, environmental etc.). This is when the 'mutation' cycle initiates and FP comes in effect. Unlike the present planning approaches and an SPO outcome, the mutation cycle is divided into mutation periods and each period has a CPO (top rows in Figure 7-4). The asset then remains current to the new set of factors that determine the asset's use at a particular span or period in time. Assuming the factors will change at some point in the future, then the mutation period will come to an end and the asset will readjust itself. The organisation will re-evaluate its business scope and identify from a pool of scenarios the most suitable CPO.

The life cycle asset optioneering activity materialises from the context of the change-readiness framework and the BIM capabilities (see previous section). The outcomes – that is, the CPOs – are stored into the asset's database, where the clients and AM teams have access post-handover to inform their decisions. The CPOs consider a range of occurring changes during the asset's lifespan which are informed by the change-readiness framework (discussed earlier). In terms of data representation, these could be models, drawings, systems, components and attributes (). The data will be stored in the BIM database, and at a later point in time, these will be available for retrieval and be used at any of the decision points shown in Figure 7-4.

The CPOs with the use of the employed BIM capabilities and through AM data capture processes will feed information back to the database, increasing the volume of data and also updating existing data. It is outside of the scope of this study to describe in detail the process of retrieving and reusing information from databases to inform decisions; however, extended research has been taken by other researchers (Demian, 2004; Masood et al., 2013). Lastly, the mutation cycle cannot be implemented if the above process is not identified by the delivery teams and the client during the early project stages of delivery.

7.7 *Mechanisms for future-proofed lifecycle development*

For efficient AM, clients and their supply partners should work together to establish an infrastructure of information delivery prior to the handover stage. The assessments that were carried for the purposes of this study showed that AM can be detached and not find support regarding the handover of data that are ‘fit for purpose’. In this instance, data that are fit for purpose are those that are produced from inception to construction and can further be used for O&M purposes post-handover within a BIM environment. AM frameworks (Taggart et al., 2014) can be effectively applied in infrastructure projects if there is (a) provision of useful information and (b) awareness that there is uncertainty hidden within the asset's lifespan.

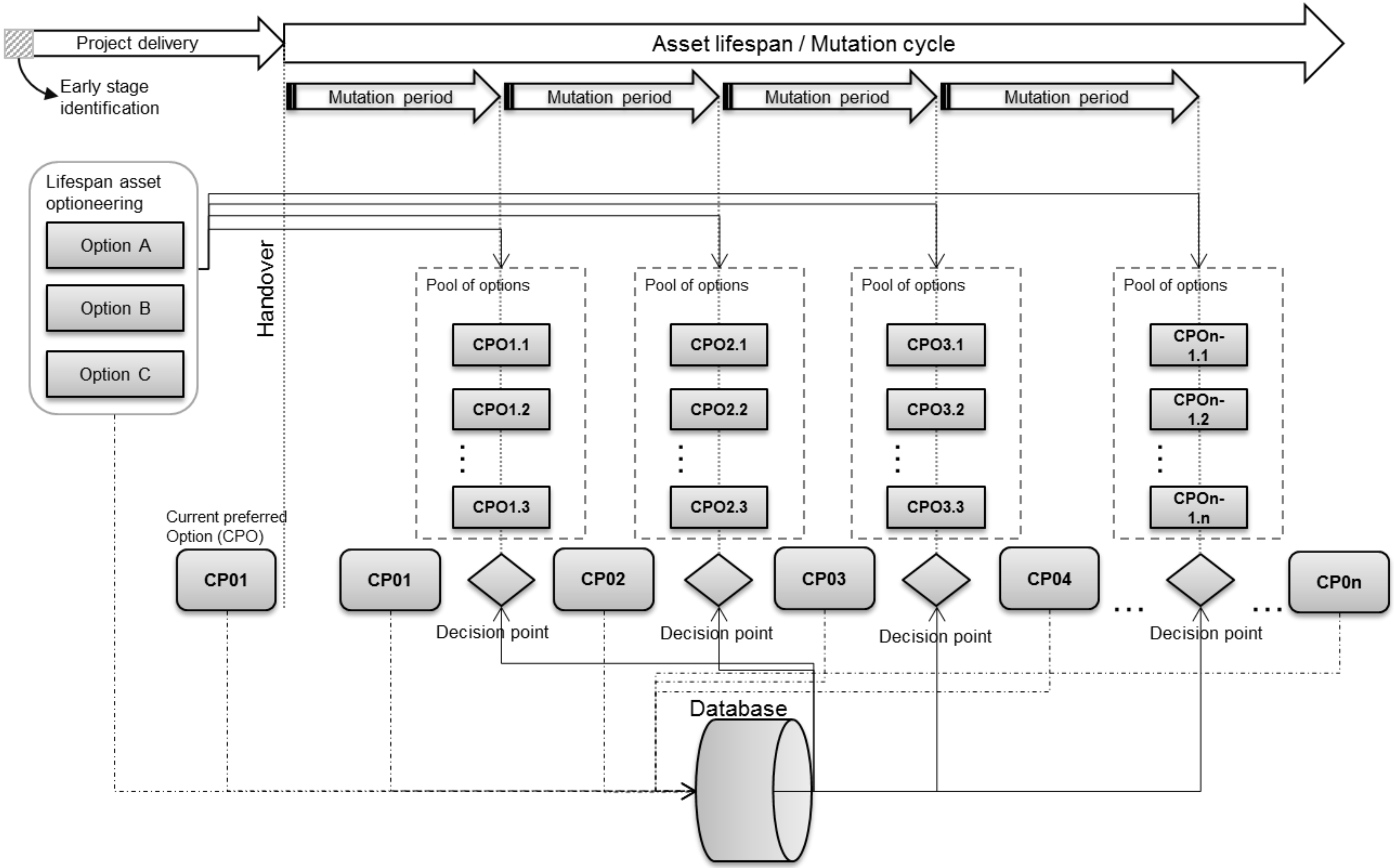


Figure 7-4: Life cycle asset optioneering and mutation asset lifecycle

Clients should push their suppliers for more holistic outcomes and target for whole-life cost reductions within their schemes. Indeed the Government mandate is that public projects should be delivered in BIM, but that does not warrant that the assets will still be fit for purpose 50 years after their completion. Nevertheless, FP should not only be about major expansions. Major savings can be accomplished by simply setting the right 'fit for purpose' data in place and in an accessible format. This will mean that other teams will be able to use and make informed decisions regarding the life of the asset. These informed decisions will originate from the data that comes with the delivered asset should not only be about major expansions. Major savings can be accomplished by simply setting the right fit-for-purpose data in place and in an accessible format. This will mean that other teams will be able to use and make informed decisions regarding the life of the asset. These informed decisions will originate from the data that comes with the delivered physical asset.

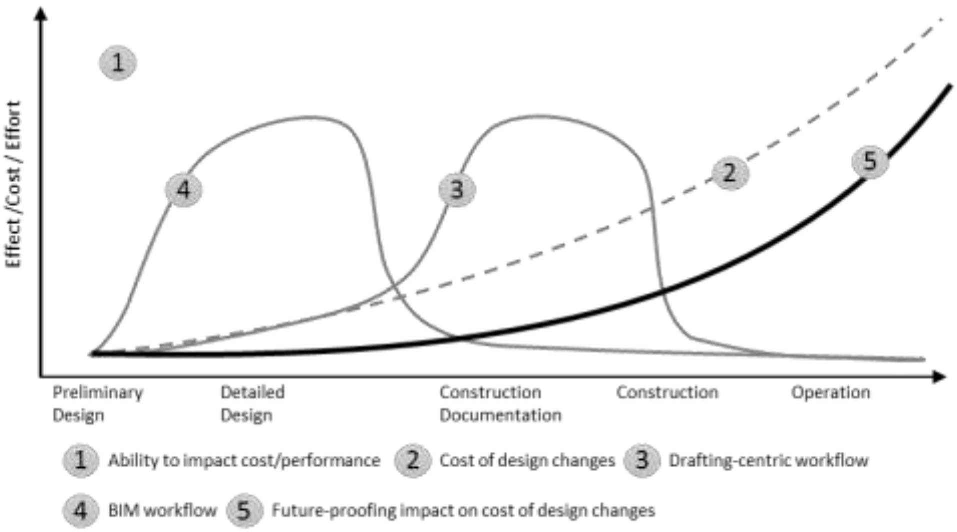


Figure 7-5: The MacLeamy Curve with future-proofing insurance ingrained in the project

Construction needs to drive towards a focus on whole-life cost reduction rather than capital cost reduction, and findings from Mevellec and Perry (2006) and Wang (2011), among others, note the importance of whole-life costing. Furthermore, it was highlighted that standardised solutions need to have embedded agility in their uses so that they can adapt. In addition, delivering projects that have the ability to deconstruct rather than being demolished is another important aspect of design, and a great example of such design approaches can be seen in King's Cross Station (King's Cross Central Limited Partnership, 2014).

The realisation that change is inevitable should question whether mandatory changes will occur too late when future requirements demand it – and thus having increased cost of changes – or ideally a 'platform of awareness' will be built in which change will occur as Hamel and Prahalad (1996) suggested, in a 'controllable environment'. This platform eventually should include a FP 'insurance' procedure and fit-for-purpose data as deliverables of this process. As shown in Figure 7-5**Error! Reference source not found.**, the cost of design changes can be reduced in the MacLeamy curve if a BIM workflow is implemented early in the project and, in addition, the project is covered by a future-proof insurance. In order to protect the assets, a series of governance measures and change in the optioneering process is suggested.

Figure 7-6: Building blocks to support future-proof Asset management decisions

7.8 *Chapter Summary*

To future-proof assets and consequently their management there is a need for the establishment of a series of high-level protection measures against uncertainty. These measures have been outlined within three agendas, namely government, strategic management and, due to the opportunities that BIM brings, information management. These agendas can be implemented only if they are supported by the BIM capabilities offered within the BIM process. Both agendas and BIM capabilities should work as building blocks that support AM. If the AM teams have access to such information, they then have valuable support and it is then possible that decisions could be taken around future-proof life cycle development. The decisions will be better supported with evidence and will be more informed, hence leading to better life cycle decisions (Figure 7-6).

To achieve the above, the teams are working on a change-readiness framework to inform the life cycle asset optioneering process. The outcomes of this optioneering activity are used to inform decisions taken throughout the mutation cycle. The mutation cycle is essentially the asset lifespan amplified with FP to withhold against uncertainty, which essentially informs the AM teams to make better decisions. As cost reductions in the construction and the sustainability agendas become more and more important, both the clients and their supply partners aim throughout the life cycle of the asset to facilitate assets that are able to respond to a mutation cycle.

Chapter 8 IPA analysis[9]: using BIM to integrate and achieve holistic future-proofing objectives in healthcare projects[10]

8.1 *Introduction*

The aim of this part of the study is to investigate the perceptions of healthcare construction experts about the use of BIM for integrating holistic FP objectives for delivering healthcare construction projects. Future-proofing (FP) as a proactive initiative for asset management is an urgent need against uncertainty, particularly in health care due to unforeseeable demographic shifts and rapid advances in medical technology. Building information modelling (BIM) is a data-driven initiative, but a rigorous analysis between them will indicate that a synergy exists. The aim of this study is to develop a classification ontology of the interactions between FP and BIM by considering the perceptions of health care construction experts. Interviews with 13 senior managers were conducted adopting the method of interpretative phenomenological analysis and an interaction matrix of BIM capabilities for implementing holistic FP objectives has been developed. The outcome is a taxonomy analysis of 30 interactions with supporting empirical evidence which was further measured quantitatively. For benefits realization in the context of BIM and FP, the industry experts recognize FP as a strategy that supports organizational and building performance. BIM drives towards life cycle operation information and data maintainability via communicating the FP strategy from a whole-life perspective and ensuring knowledge transfer across all stages. Health care operators and construction experts should be able to benefit from this taxonomy analysis as an aid to planning for FP throughout their BIM processes.

8.2 *Future-proofing aspirations*

The views of the interviewees with regard to aspects of FP have been summarised into eight categories (Table 8-1). Thirteen interviews took place[11] with senior managers with experience in healthcare construction. The analysis of this section was made in a two-step process where the transcripts were analysed using

[9] *Please refer to Section 5.6.4 for a thorough review of the method used in this chapter.*
[10] *The findings of this study have been published (please see Appendix E)*
[11] *Please refer to Appendix I for the Interview form used in one of the interview sessions*

Interpretative Phenomelogical Analysis (IPA). IPA is described in depth in Section 5.6.4. The eight categories here emerged directly from the IPA. Each category reflects one particular capacity of FP. The eight aspirations are discussed herein detail and, in Table 8-1, the FP tasks that emerged from the interview sessions are documented.

1. *Setting of initial FP targets*: The interviewees suggested that the setting of initial targets should be around establishing the principles for FP in their design strategy. Those principles consider various aspects, e.g. investigation of future services, clients' information requirements regarding considerations, standardization agenda, etc.
2. *Investment options:* FP considerations can be used for portfolio and asset management. The interviewees highlighted awareness around business opportunities that may rise in the future of an operating health care asset and how these may reflect in the asset. The opportunities consider future collaborations with nearby private providers and distribution of services accordingly, provision of unused spaces for patient welfare, etc.
3. *Adaptive to FP needs procurement method:* Contractual agreements seem to hinder aspects of the concept and the interviewees highlighted particular parts of current methods they believed will enhance it. Among others, fast track was mentioned as a method suitable for addressing uncertainty (although it was recognized that adoption may increase costs by 20%), which is also highlighted in (Bogus et al., 2006); the PFI as an example of extending the brief and IPD for involving the FM as early as possible (for instance offices) concrete frames and open spaces have been mentioned among others.
4. *Necessary building flexibility:* An integral part of FP is having flexibility incorporated in the design. Speaking from experience the interviewees filtered the most useful concepts of flexibility that are usually used when delivering healthcare facilities. Sacrificial systems (i.e. walls with no M&E systems input) and soft spaces (i.e. offices), concrete frames and open spaces have been mentioned among others.

5. *Healthcare-specific design scenario factors:* The interviewees identified the tasks they perform when looking at 'what-if' scenarios during the design process. Aspects such as hospital activity, projections, patients flow, room adjacencies etc. are some of what was identified by the interviewees to develop their business case.

6. *Repeatable standardised spaces:* Although at first sight, standardization may seem to contradict flexibility, there are particular features that make standardization attractive for delivering futureproof solutions. For example, employing limited general NHS rooms was found to allow an existing space to be used for other uses. Repeatable spaces which improve service delivery (i.e. increase familiarity to staff coming from other hospitals) were mentioned too.

7. *'What-if' data for maintenance solutions:* The data provided early in the project should be used to better support the FM decisions at the operational stage. Data such as maintenance equipment factors, projections of future use and how these will affect service maintenance could be incorporated into information exchange packages which may be used at later stages.

8. *Adaptive management:* Lastly, the interviewees highlighted the importance of adaptive management for FP solutions. For example they suggested that lessons learnt from other sectors (e.g. oil and gas, and the automotive industry) where the production environment is always adaptable to new products (i.e. development of new cars while the workflow of existing cars continues) should be used as example to improve processes in the healthcare sector.

8.3 *Holistic Future-proofing objectives*

After interviewing the healthcare construction experts, the FP tasks presented in Table 8-1 emerged and were later compared against the tasks found in the literature (Table 3-1). These two sources of FP tasks were combined to draw out the following FP objectives (Table 8-2). At the top of the hierarchy, the FP objectives represent the overall scope of each category and are decomposed into tasks for each specific setting. These tasks focus solely on implementing FP strategies and are intended to be used alongside standard procedures (e.g. CIC Scope of Services) when delivering a project. Compared to the FP aspirations presented in the previous section (Table 8-1),

Table 8-1: Future-proofing aspirations in healthcare projects

FP Aspirations	FP tasks	Label
Setting of initial FP targets	Investigation of future services (home based treatment, remote care, themed treatment etc.)	K1
	Client awareness for FP requirements, earlier in discussion	K2
	Earlier consideration of the asset operation	K3
	Standardisation initiative	K4
	Regional requirements consideration	K5
Investment options	Collaborations with private healthcare and revenue for the NHS	K6
	Provision of commercial spaces for patient welfare	K7
	Identify where investment now will save money later (whole-life costing earlier in discussion)	K8
	Towards corporate identity	K9
Adaptive to FP needs procurement method	Fast-track mentality-build for overlapped activities (i.e. big floor plates, ducts on regular basis)	K10
	Brief extended to project's lifespan (PFI)	K11
	Documented opinion of maintenance providers (IPD)	K12
	Evaluation of design and construction decisions and materials selection	K13
Necessary building flexibility	Finding commonalities	K14
	Filtering spaces that can be changed/cannot be changed	K15
	Increasing clinical space/decreasing non clinical	K16
	Sacrificial systems	K17
	Finding differences among projects	K18
	Concrete frame more flexible than steel frame	K19
	Exterior prepared for expansion	K20
	Flexibility dependable on cost and complexity of the room	K21
	Long- mid- short- term elements of flexibility	K22
	Open spaces	K23
	Soft spaces	K24
Healthcare-specific design scenario factors	Activity projections	K25
	Commissioning of services	K26
	Future services, future treatments	K27
	Patients flow	K28
	Room adjacencies	K29
	Room usage data	K30
Repeatable standardised spaces	Employing limited universal repeatable spaces	K31
	Multi use (agile spaces) for whole life cost reduction	K32
	Repeatable spaces to improve service delivery	K33
	Standard specs for construction elements	K34
'What-if' data for maintenance solutions	Conditional levels of equipment linked to criticality	K35
	Criticality of equipment and services	K36
	Projections of future use for maintenance decisions	K37
	Maintenance equipment factors	K38
	Data relevant to maintenance teams (e.g. what type of change, how to deal, when to deal, how to do it etc.)	K39
Adaptive management	Adaptation of processes from other sectors	K40
	Representations of how FP is linked to clinical efficiency	K41
	Sophisticated health trends data	K42
	Whole-life decisions at every stage	K43
	Use of evidence for estimation of changes	K44
	Minimum disruption of services	K45
	Estates managers are aware of FP strategy	K46

the objectives provide guidance on what deliverable is required at a particular phase. Future-proofing delivery is gradually developed at all phases which means that objectives found in each phase replace those from the phase before.

Table 8-2: List of FP objectives and tasks assigned to them

Phase and FP objectives	**Labels**	
Planning	Literature (label column of Table 3-1)	Interviews (label column of Table 8-1)
P-I: FP brief setting	P1-P6	K1-K3, K5
P-II: Investment and portfolio agenda	P7-P10	K6-K9
P-III: Adaptive-friendly procurement method	–	K10-K13
P-IV: Identification of flexibility	P11-P18	K14-K16, K18, K20
P-V: Responsiveness of government strategic goals	P19-P22	–
P-VI: Healthcare scenario factors	P23-P24	K25-K30
P-VII: Standardisation agenda	–	K31, K33
P-VIII: Use of resources	P25-P26	–
P-IX: Whole-life assessment	P27-P28	K21, K32, K40, K43
P-X: Knowledge systems	P29	K35, K36, K38, K42
P-XI: Healing environment	P30-P35	K45
Design		
D-I: Demonstrating change-readiness of design	D1-D7	K22, K23, K24
D-II: Demonstration of maintenance plans	D8	K39
D-III: Demonstration of flexibility plans	D9-D10	K19, K41
D-IV: Generic spaces & elements	D12-D15	K34
D-V: Demonstration of disruption plans	D16-D19	K17
Construction		
C-I: Publication and application of FP strategy on site	C1-C2	–
C-II:- FP of working conditions	C3-C4	–
Operation		
O-I: Awareness of FP strategy	O1-O2	K46
O-II: Feedback for future-proof project	O3-O4	K37
O-III: Reuse of components and materials	O5	K44

The objectives are grouped under each project phase as follows:

Planning

In this phase, the FP strategy is defined and the most important decisions are discussed to set the foundations for the subsequent project phases. Future changes and investments are investigated at conceptual level.

- *P-I: Future-proofing brief setting:* Future-proofing needs to be brought into the discussion at the very early stages and be included clearly in the business case. The clients should clarify their FP goals to the design consultants and contractors.

- *P-II: Investment and Portfolio agenda:* According to the interviewees FP should not only consider how spaces could be adaptable to operational changes; it should also identify investment opportunities within the facility itself and across the wider location of the building.

- *P-III: Adaptive-friendly procurement method:* The procurement method should allow the core principles of FP to be implemented, and as such it is essential to adopt and merge some of the unique benefits that have been identified in most of the existing procurement methods (for instance PFI's contractor's involvement throughout project's lifespan, P21+ introduction of standardised generic components etc).

- *P-IV: Identification of flexibility:* The core principles of FP are *flexibility* and *adaptability*. These two need to be identified and discussed as early as possible and should be defined in terms of future user behaviours and needs.

- *P-V: Responsiveness of government strategic goals:* Due to the criticality of these projects, the supply side and the clients should agree that going beyond the standards (for instance the Building Regulations) is sensible to ensure sustained quality delivery to patients and staff.

- *P-VI: Healthcare scenario factors:* Healthcare experts reported that testing room adjacencies; documenting activity projections; commissioning of services; patients flow; and room usage data etc. is essential to design successful healthcare projects.

- *P-VII: Standardisation agenda:* The interviewees believed that standardisation should also drive towards corporate identity, thus ensuring that patients will receive a consistent standard of quality of services.

- *P-VIII: Use of resources:* When designing healthcare facilities, the designers need to consider the distribution of resources across the health service and consider applied changes to the existing system and how these will reflect on the space that is provided.

- *P-IX: Whole-life assessment:* According to the respondents, flexibility provision depends on cost, thus it should be considered what the effect of flexibility will be in terms of whole-life cost evaluation when it is introduced in the design.

- *P-X: Knowledge systems:* Important factors such as criticality and conditional levels of equipment (mainly for maintenance) are considered. The interviewees suggested that it is important to collect more sophisticated health data about trends, for example data specific to the region's future needs with regards to health services.

- *P-XI: Healing environment:* In terms of FP, the supply chain members need to note in their plans that any future scenarios should not hinder considerations of such spaces.

Design

When proceeding in this phase, all planning objectives become visual representations and richer documentation should be produced to allow easier communication of FP. This phase and the subsequent one reflect this notion:

- *D-I: Demonstrating change-readiness of design:* The design team focuses on the design implementation of accommodating the changes the asset will undergo throughout its lifespan.

- *D-II: Demonstration of maintenance plans:* The interviewees who are involved in the operation phase emphasised the importance of maintenance strategies in asset management, and if not planned with care maintenance costs can be up to 10 times higher than construction cost.

- *D-III: Demonstration of flexibility plans:* A clear demonstration of how flexibility is introduced within the asset is required to capture the strategy that was decided in the previous Planning phase.

- *D-IV: Generic spaces and elements:* Generic spaces (rather than bespoke rooms) that have built-in agility and can easily and cheaply be modified into most types of NHS rooms were suggested by the interviewees.

- *D-V: Demonstration of disruption plans*: This objective is to ensure that future upgrading will be done with minimum disruption of uses. Disruption plans refer to the physical elements of the asset.

Construction

In this phase, FP takes on a physical manifestation. The final product is still underway, thus it is still necessary to communicate any FP aspects to the construction stakeholders.

- *CO-I: Publication and application of FP strategy on site:* FP aspects might not be obvious in a design drawing, or any necessary on-site changes need to be checked that they do not intersect with the FP requirements.

- *CO-II: FP of working conditions*: FP does not only respond to organisational changes. On-site construction conditions should also be future-proofed in the same way changes are addressed within the organisation.

Operation

The final phase of the project works as an evaluation for the effectiveness and efficiency of FP. The end users have an active role and note which practices work best and which do not in order to suggest improvements to the FP strategy. The strategy must continue to evolve during the operation phase in the same way other frameworks do (i.e. Soft Landings).

- *O-I: Awareness of FP strategy:* The end users need to be aware of the FP strategy. All the information that was produced in the previous phases should be handed over and demonstrated to the end users.

- *O-II: Feedback from future-proof project:* The end users (building occupants) have an active role regarding the building's lifespan in terms of evaluating its performance and effectiveness in its ability to adapt to the forthcoming needs.

- *O-III: Reuse of components and materials*: In case of demolition, the strategy should ensure as many as possible components and materials can be reused in a new project. In addition, lessons learnt should be drawn and later used as evidence to inform future FP strategies.

8.4 *BIM capabilities for FP*

This section describes BIM capabilities that relate to FP as identified by the healthcare experts and the categories are summarised in Table 8-3. The specific interactions have been grouped into these six capabilities and reflect the specific areas where BIM is used for implementing FP. Additional BIM capabilities exist and have been documented in the literature (for example Eastman et al. 2011; Sacks et al. 2010), but not all of these necessarily add value to FP in the experts' opinion. Identifiers are added in Table 8-3 (first column) which refer to subsequent tables where further description of the 30 interactions that have emerged for FP and BIM is given.

Table 8-3: BIM capabilities related to future-proofing

Reference table	BIM Capabilities for FP
Table 8-4	Flexible data
Table 8-5	Optioneering capabilities
Table 8-6	Project evaluation
Table 8-7	Standardised space catalogues
Table 8-8	Whole-life communication
Table 8-9	Whole-life costing

8.5 *Generation and interpretation of the BIM – FP Interaction matrix*

The FP-BIM framework is reviewed to test the support of the identified BIM capabilities (Table 8-3) to the holistic FP objectives (Table 8-2), as shown in **Error! Reference source not found.**. The matrix can be interpreted in many ways and valuable conclusions can be extracted regarding the synergy between FP and BIM. Some of the interactions reflect project management interests, some design and construction issues and some reflect operation interests. The index numbers in the cells of **Error! Reference source not found.** express an understanding of the BIM uses to implement FP; the numbers are explained in the key tables Table 8-4 to Table 8-9.

The cells are shadowed and reflect the level of association between a BIM capability and a FP objective and thus when a cell appears in a darker colour it means that the FP objective highly benefits from that BIM capability (many interactions support the objective); for light shaded cells there is less to no association (see label in **Error! Reference source not found.**). In addition, Table 8-4 to Table 8-9 use evidence from practice to support the identified interactions that emerged.

The FP objectives with the most interactions were found to be *P-IV: Identification of flexibility* (18) while *P-I: FP brief setting* and *D-III: Demonstration of flexibility plans* shared 17 interactions each. In addition, the implementation of D-III objective was found to be highly related to multiple BIM capabilities (4), while P-I and P-IV were found to be highly associated to (3) BIM capabilities each.

The BIM capabilities with the most interactions across a project's life-cycle were found to be *Whole-life communication* (64), *Flexible data* (40) and *Standardised space catalogues* (39). More specifically, *Whole-life communication* and *Flexible data* were found to have interactions in all FP objectives but one. The interactions that appear the most are *Adaptable data for various actors* (15), *Benchmarks and recommendations* (14) and *Reducing the cost of resources* with 13 interactions.

The objectives with the least number of interactions were *P-III: Adaptive-friendly procurement method* (0), followed by *CO-II: FP of working conditions* (3), and *Responsiveness of government strategic goals* (6); the healthcare experts could not associate those objectives with any of the identified BIM capabilities. There could be several reasons for this: the experts do not find it useful to use BIM for such objectives, or they are not aware of how to use for these objectives. The weakest BIM capability was found to be *Whole-life costing* (26) when compared to the other capability categories.

FP capabilities against BIM capabilities

BIM capabilities	Future-proofing objectives: Planning											Design					Construction		Operation		
	P-I	P-II	P-III	P-IV	P-V	P-VI	P-VII	P-VIII	P-IX	P-X	P-XI	D-I	D-II	D-III	D-IV	D-V	CO-I	CO-II	O-I	O-II	O-III
Flexible data	1-5	2		2-4	3	2,3,5	5	3	1,4	2,3	3	3	2-4	3	5	2,3	1-3	2,3	1-4	1,4	3,4
Optioneering capabilities	6-9	7,8		6-9		6-9	9	8	7,9	8	7,8	6-9		6-9	9	7	7			8	8
Project evaluation	10-12	11,12		10-12	10, 11	10-12	10	10,11	10-12	11	10	10,12	10	10-12		11	10		12	10-12	10
Standardised space catalogues	19	17		13			13-19	14-16	15,17, 19	14,16	14, 16,18		14-17, 19	16	13,15, 17-19	15,19	17		14-16		19
Whole-life communication	21,22, 24,26	20,26		22-26	20, 24	22, 24-26	21,22, 24,25	20,26	20,22	21,22	24,26	22-27	21, 23-25	22-26, 27	22,23, 25,26	20-21, 23-26, 27	20-22, 24-26, 27	27	20-22, 26	20	25
Whole costing	30	29		28-30	30		30	30	28-30	30		28	30	28-30	28,30	28-30	28			29,30	30
Label	no association	low	moderate	high																	

Table 8-4: Flexible data - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
1	Gradual data - Data production aligned to each phase	"At the end of Stage 5 in construction you want the COBie data to include … a serial number of every single light in that four bed bay. You do not need that at Stage 2 though. At Stage 2, COBie is there to tell you that there will be a light which gives around 1000 lumens."
2	Expanded use of BIM to non-design tasks	"The ability to give the data of what real life is. E.g. a light bulb with all the real specifications; if I need to get a replacement I want to be able to print a shopping list and just go a get a buy it."
3	Adaptable data for various actors	"The data that a model carries can be used for a whole range of different subjects. From logistics, safety walkthroughs, visualizations, material take off etc. but it is not a different set of data."
4	Maintained data availability	"The key from my point of view is ensuring the information will exist in an existing facility in a form that can be reused 3, 5, 10 years down the track."
5	Online live databases linked to the model	"The idea is to build a BIM library of standard components and therefore you do not need to design the bedroom. What we actually did is having three standard bedrooms. All P21+ are going to be using just three models."

Table 8-5: Optioneering capabilities - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
6	Collaborative 'what if' scenarios	"BIM is a process which allows all actors to work on various scenarios on the same model. All the components put in by the different disciplines can be seen and tested within the virtual model."
7	Design integrity	"Inevitably it does not matter how much you do in 2D if somebody will forget that that column is actually there, whereas in BIM you cannot simply forget that."
8	Multi-purpose scenarios	"I think there is the case of having the design package on one end, and the software packages that look at flows and occupancy levels on the other end and then joining them together."
9	Quicker check of design alternatives	"Now it is much quicker [the design process] and because it is quicker we can manage our risk better because … we are looking at those optioneering possibilities and because we are able to put all those influences and drivers into the equation."

Table 8-6: Project evaluation - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
10	Benchmarks and recommendations	"You can't do any other way that it is quicker than the confidence of using BIM and you can find where the sensitivities are in the design."
11	Comparison of existing condition against future requirements	"I would want to know the 3D size of the space, what is in the space and how it worked. Patient flows that have been assumed. If I've got that information in place, when I then in the future start to reconsider those variables I can then successfully remodel what I currently have against my new requirements."
12	Quantification of FP	"But because you could develop a BIM model and then use it to demonstrate at the early stage of the design process the end use of the facility and be able to say that not only have we thought about FP, we can actually quantify FP."

Table 8-7: Standardised space catalogues- Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
13	Have something to work with – not starting from scratch	"When you create a BIM model you are constructing it in a sense you can do it more quickly and more efficiently if you are dragging big component parts out of a catalogue rather than starting from scratch."

14	Increases familiarity of staff with workspace	"When staff is moving from one hospital to another there are actually no unfamiliar spaces so they can do their work more efficiently. So we are able to say how design is not mirrored it is repeated, i.e. the bed is always on the left for example and the clinical zone is always on the patients right hand side."
15	Minimises the need for disruptive stakeholder engagement	"It will reduce the amount of stakeholder engagement that is required therefore you do not have to take the clinicians away from their day jobs to be designing bedrooms again. These will be available as BIM data drops to be used."
16	Reduction of clinical errors	"There are also benefits to staff because those that have familiarity of the room and know where equipment is placed… so you have links to reduce clinical errors, when you have all these sort of design features being repeated."
17	Supply chain cost reduction	"And when use those [same] spaces in BIM you could then share that BIM information with the suppliers and the suppliers would hold that information which would cut their cost as well."
18	Repeatable design is linked to evidence and experience	"An anecdote were consultant X always knows what he wants e.g. six single beds etc. because that is how he has done for the past 20 years …but there are no actual evidence what he wants is going to help the patient so what we have done is to try and take the subjectivity away."
19	Specifications become default and automated input	"Regarding FP at least if we get our components right we can clarify our standard specifications, we can cut a list of element together … into the BIM model almost automatically, on the drawings, it will be on the business spec etc."

Table 8-8: Whole-life communication - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
20	Virtual representation and roadmap of FP	"[BIM] is the most efficient way of achieving FP and also the most efficient way of communicating that to the stakeholders because you can actually show them the 3D spaces and you can actually have a road map for what you got there. And it can all be edited in space."
21	Operational knowledge	"I am immediately thinking of operational knowledge because e.g. we operate a hospital as of today and there will be 40 people running that project, they will all have a massive amount of knowledge about what works well in that hospital… if we could link that feedback from people actually using the hospital back to BIM databases."
22	Communication of working specifications	"I would like to know about adjacencies. In a healthcare environment I think it would be information from the healthcare professional and where they think and how a hospital is going to work in the future."
23	Fully multidisciplinary integrated model	"This is all about looking at a full integrated model, bringing the right aspects e.g. fire engineering, so that you have got a model that reflects good fire engineering practice; that shows how the services function, it shows you patient flows, visitor flows etc."
24	Non-physical presence for design reviews and workshops	"The days of actually having a great big workshop in a great big room and inviting lots of people that is probably going to be unnecessary and things are going to be more virtually between teams."
25	Standardised information process flows	"With BIM you can build an international team, e.g. with the airbus various components are built by various teams in various countries and it is all transported to France where it is being assembled. The process is accomplished by a multinational team."
26	Volumetric process-understandable by non-experts	"The process becomes volumetric. We can model a room and present it to the client. That gives them confidence of how something can work on a particular way."
27	Visual precaution tool	"…a lot of those problems have to be solved with an expense <u>on site</u> and BIM is trying to reduce that cost."

Table 8-9: Whole-life costing - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
28	Classes minimisation-cost savings	"BIM can improve the clashes within the construction because the Mechanical engineer will be more aware of what the architectural drawing will look like. If they sort it out in the BIM model in the first place, then when then they actually build it they will get the services around the installed components because they will know about it."
29	Cheaper check of alternative solutions	"FP is possible with BIM and it will enable us to model a building with different given parameters more quickly and cheaply than otherwise."
30	Reducing the cost of resources	"In your BIM model you could have those scenarios and you could then optioneer those and check what is the most efficient way to provide a space now which meets most of those scenarios with the least additional cost [of resources]."

8.6 *Observed benefits when implementing FP and BIM*

In literature, the two concepts are presented as two different initiatives and are not interconnected although they both seem to be focusing on change. Based on this, a classification ontology was created for assessing the interactions of the two concepts in question as they emerge in the health care built environment. The findings are twofold: a holistic approach to the concept of FP is provided. A list of objectives and tasks provides a thorough approach to FP as a delivery concept as opposed to being solely a design (NHS Confederation 2005; DH 2013), sustainability (Krygiel and Nies 2008; Georgiadou et al. 2012) or investment solution (World Bank, 2010). In addition, a metacritique analysis of BIM was presented and the strengths and weakness of this process as it is reflected in the implementation of FP are presented.

The 30 interactions were found to be repeated have been counted a total of 237 times across the FP-BIM framework in **Error! Reference source not found.**. In terms of how a future-proofing strategy is progressing across the project stages the findings suggest it is at the early design stages where the preparation against uncertainty occurs regarding the asset life.

For benefits realisation in the context of the two concepts, after distilling the 30 interactions it can be concluded that whole-life communication is the most relevant capability of BIM for implementing future-proofing and thus the objectives can be clearly communicated within the project's lifespan. The interviewees could better associate the objectives to organisational and building performance through BIM. In addition, BIM supports the development of lifecycle operation information via becoming a communication platform and thus ensuring 'data maintainability'

Future-proofing and 'traditional' project data are being produced at a similar pace and during the operation stage additional operation data are being captured which results in information that supports and updates / maintains the adopted future-proofing strategy. In contrast, BIM for whole-life costing has not yet matured and more investigation is required. The above are summarised in Figure 8-1.

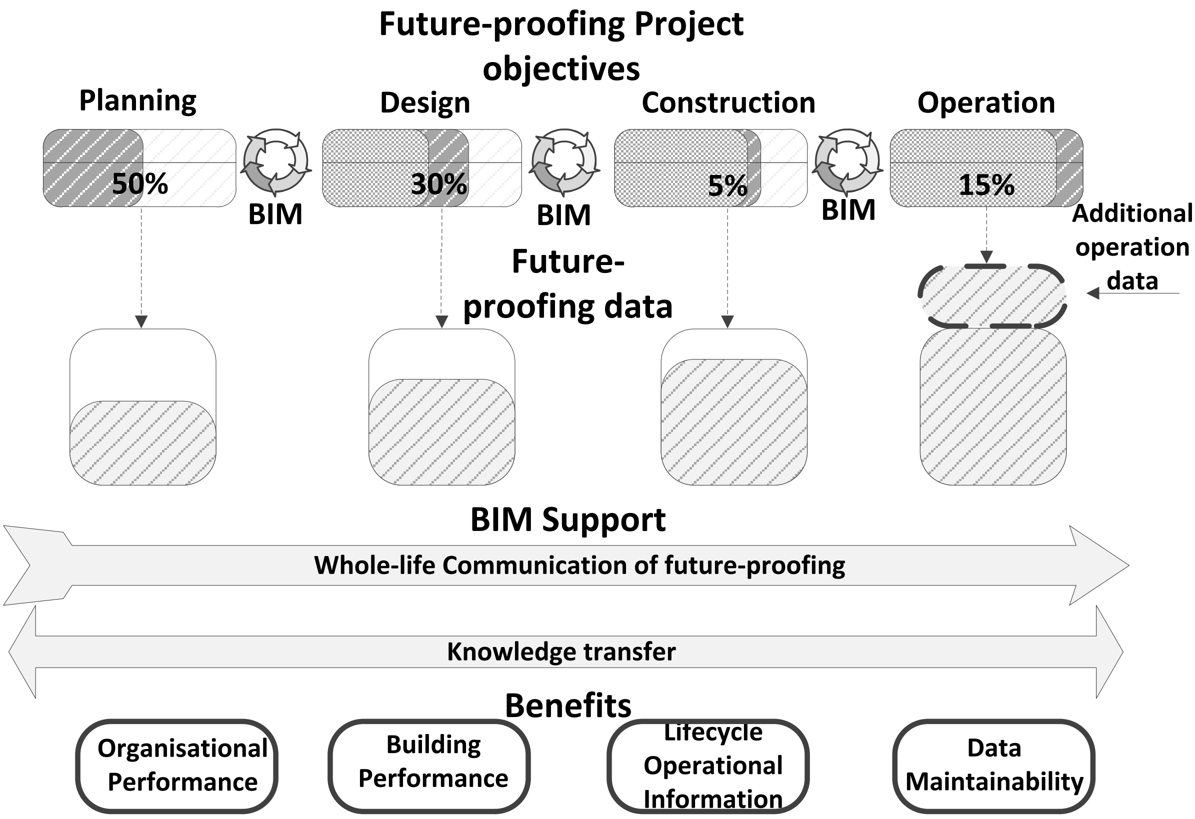


Figure 8-1: Benefits realisation for implementation of FP using BIM

8.7 *Chapter Summary*

This chapter presents a holistic process of implementing FP by identifying a comprehensive set of FP objectives and tasks across the project and asset lifecycle. The 30 interactions, presented in this study are further supported with evidence from practice and demonstrate the strong synergy between BIM and FP in healthcare construction projects. One limitation is that for projects with less complexity, BIM might in fact cause more challenges than benefits.

BIM processes drive rather than simply enhance FP implementation and that derives from an 'all-inclusive' observation of the emerged interactions. BIM is used as the vehicle for delivering FP objectives at all phases and many of the interactions are repeated - carried over - from one phase to the next. BIM itself is not a concept with clear start and end times in project management; it is a multifaceted ongoing process where its capabilities are used to support and improve many concepts found in the built environment.

In addition, the taxonomy is supported with empirical evidence which showcases in detail the practical issues faced in projects implemented in BIM and future-proofing. Much like the equivalent interconnections between BIM and lean (Sacks et al., 2010) the findings imply that delivery teams and clients working on encompassing future-proofing in their delivery strategy should ensure that their processes are adapted to meet the BIM principles.

On the other hand, the high number of interactions may suggest that a step change is required to include future-proofing in a BIM project and converserly any project that is targeting future-proofing implementation may face a step change to adopt BIM processes. Due to the high interaction across all stages it may be challenging to adopt one concept at early stages and then introduce the other at a later stage.

Chapter 9 Triangulation analysis: proposal of enterprise future-proofing deployment for Healthcare Organisations

9.1 *Introduction*

The National Health System (NHS) in England is going through a process of adapting to an ever-changing environment. The recent Francis report message was that the NHS must change how it works in order to put patients first. This suggests that the organisation has once again disregarded all the assumptions and traditions of the way business is done, and re-engineers its processes to achieve better performance. In this context, future-proofing (FP) as a measure against uncertainty is introduced complemented by adoption of innovation. This chapter proposes a change management model (Figure 9-2) for future-proofing deployment for the healthcare construction industry and further identifies organisational competencies and strategic capabilities that emerge from the implementation of FP and BIM in healthcare.

9.2 *Literature review: internal and external factors*

Literature review in Chapter 2 presented uncertainty as it emerges in Healthcare policies and thus having a direct effect in healthcare asset design life. The literature review explored the following two main areas.

- *External factors:* these factors require an immediate response by the organisation and management team, often in the form of organisational change. These factors occur are outside of the control of the organisation, yet can cause changes inside the organisations' structure and form.

- *Internal factors*: These are factors mainly controlled by the organisation, and are frequently associated to the organisation's leadership, re-engineering of business plan, culture etc. The internal factors are the correspondence of the organisation to the external factors it has to face.

The internal factors that have been identified in the literature review are:

- demographic trends: fertility, migration, mortality

- changing patterns of disease: chronic diseases, infectious diseases, new diseases; and
- technological advances and patterns of care: surgical processes, medicine, equipment, operation cost.

The internal factors that have been identified in the literature are:

- advances in healthcare policy: changing services, capital investment, cut of costs, new forms of contract;
- distributing layers and optimal size: local population, infrastructure demand, average length of stay, specialisation care, resources; and
- aggressive proactive response: fixed design delivery, design teams not involved, brainstorming scenarios, flaw of averages, forecasting, theory apart from practical completion.

The external factors represent the first part of a push-pull interaction between public health trends and the NHS response has been highlighted. The present methods of reactive approaches are outlined. Demographic trends such as fertility, mortality, migration and ageing population are discussed by observation of past data. Other themes are explored and the discussion continues in reviewing different patterns of disease and care and how epidemics such as heart disease drive medical technology to new innovations and thus advances in medical technology and clinical knowledge are discussed.

The internal factors focus on government policy and specifically into how the NHS is changing its healthcare services in order to deal with the above trends. Further discussion follows about issues such as distribution of layers and optimal size, forecasting and factors that lead to uncertainty. The discussion proceeds around how forecasters and health managers are making predictions regarding future demand and identifying possible future scenarios.

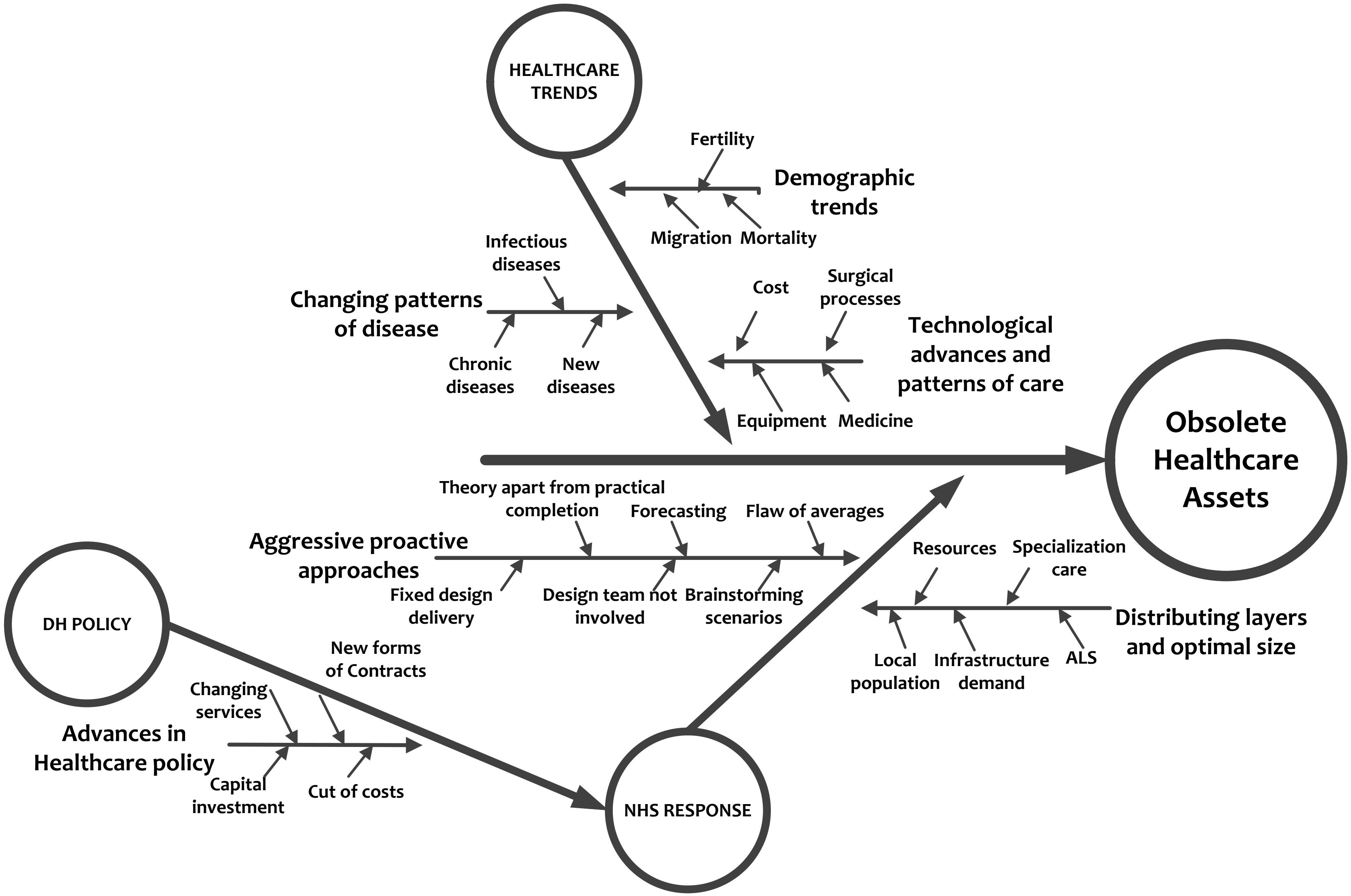


Figure 9-1: Internal and external factors resulting in obsolete Healthcare assets

9.3 *IPA review: Future-proofing Competencies*

According to Mahadkar (2012), "[c]ompetencies are used as the building blocks which begin to address gaps around informed decision making for healthcare infrastructure planning". Competencies are an essential element in developing change management models for an organisation's performance and way forward. There are various levels of competencies within an organisation, and in literature is an often misunderstood term with many meanings and uses.

Organisational competencies is a term that has been used in the area of performance management for many years. It is a common term used in human resources and by organisational change consultants to describe employee skills the organisation must have to achieve its plans (Cullen Coates & Associates, 2008). In addition, Coates (2008) argued that instead, an organisational competency is a term that describes *"the compelling cross-company core competencies that drive integrated business execution and management alignment".*

In healthcare, the NHS (2009) has distinguished competencies into two categories: organisational and individual competencies. The first describes the commissioning processes and capabilities that when developed to a high level will enable the organisation to deliver improvements in health outcomes over time. On the other hand, an individual competency covers the behavioural and knowledge skills the employees need to have to achieve a particular outcome. There are currently 20 identified individual competencies (NHS, 2009).

The World Class Commissioning Programme (WCC) is an example of organisational competencies. The programme *"is a set of mutually reinforcing policies, development programmes and assurance systems put in place by the Department of Health in England. The programme describes in detail 11 competencies which have been assessed for each primary care trust"* (Sobanja, 2009). These competencies have been identified by the DH and its purpose is to place an assurance programme for the department to meet its vision and objectives (Table 9-1).

Table 9-1: World class commissioning competencies (NHS, 2009)

WCC competency	WCC sub-competency
1) Locally lead the NHS	1a) Reputation as the local leader of the NHS
	1b) Reputation as a change leader for local organisations
	1b) Reputation as a change leader for local organisations
	1c) Position as an employer of choice
2) Work with community partners	2a) Creation of Local Area Agreement based on joint needs
	2b) Ability to conduct constructive partnerships
	2c) Reputation as an active and effective partner
3) Engage with the public and patients	3a) Influence on local health opinions and aspirations
	3b) Public and patient engagement
	3c) Improvement in patient experience
4) Collaborate with clinicians	4a) Clinical engagement
	4b) Dissemination of information to support clinical decision making
	4c) Reputation as leader of clinical engagement
5) Manage knowledge and assess needs	5a) Analytical skills and insights
	5b) Understanding of health needs trends
	5c) Use of health needs benchmarks
6) Prioritise investment	6a) Predictive modelling skills and insights to understand the impact of changing needs on demand
	6b) Prioritisation of investment and disinvestment to improve population's health
	6c) Incorporation of priorities into strategic investment plan to reflect different financial scenarios
7) Stimulate the market	7a) Knowledge of current and future provider capacity and capability
	7b) Alignment of provider capacity with health needs projections
	7c) Creation of effective choices for patients
8) Promote improvement and innovation	8a) Identification of improvement opportunities
	8b) Implementation of improvement opportunities
	8c) Collection of quality and outcome information
9) Secure procurement skills	9a) Understanding of provider economics
	9b) Negotiation of contracts around defined variables
	9c) Creation of robust contracts based on outcomes
10) Manage the local health system	10a) Use of performance information
	10b) Implementation of regular provider performance discussions
	10c) Resolution of ongoing contractual issues
11) Make sound financial investments	11a) Measuring and understanding efficiency and effectiveness of spend
	11b) Identifying opportunities to maximise efficiency and effectiveness of spend
	11c) Delivering sustainable efficiency and effectiveness of spend

The identified competencies that emerged from the data collection process should be used complementary to the world class and individual competencies that were discussed previously. The hierarchical structure can be interpreted as shown in Figure 9-3. The FP competencies are the 'thin layer' between the Department's vision and the organisational competencies. This is because their concept is partly covered amongst the organisational competencies and partly they go beyond the scope of the organisational competencies; meaning their outcome is for the design life of the asset.

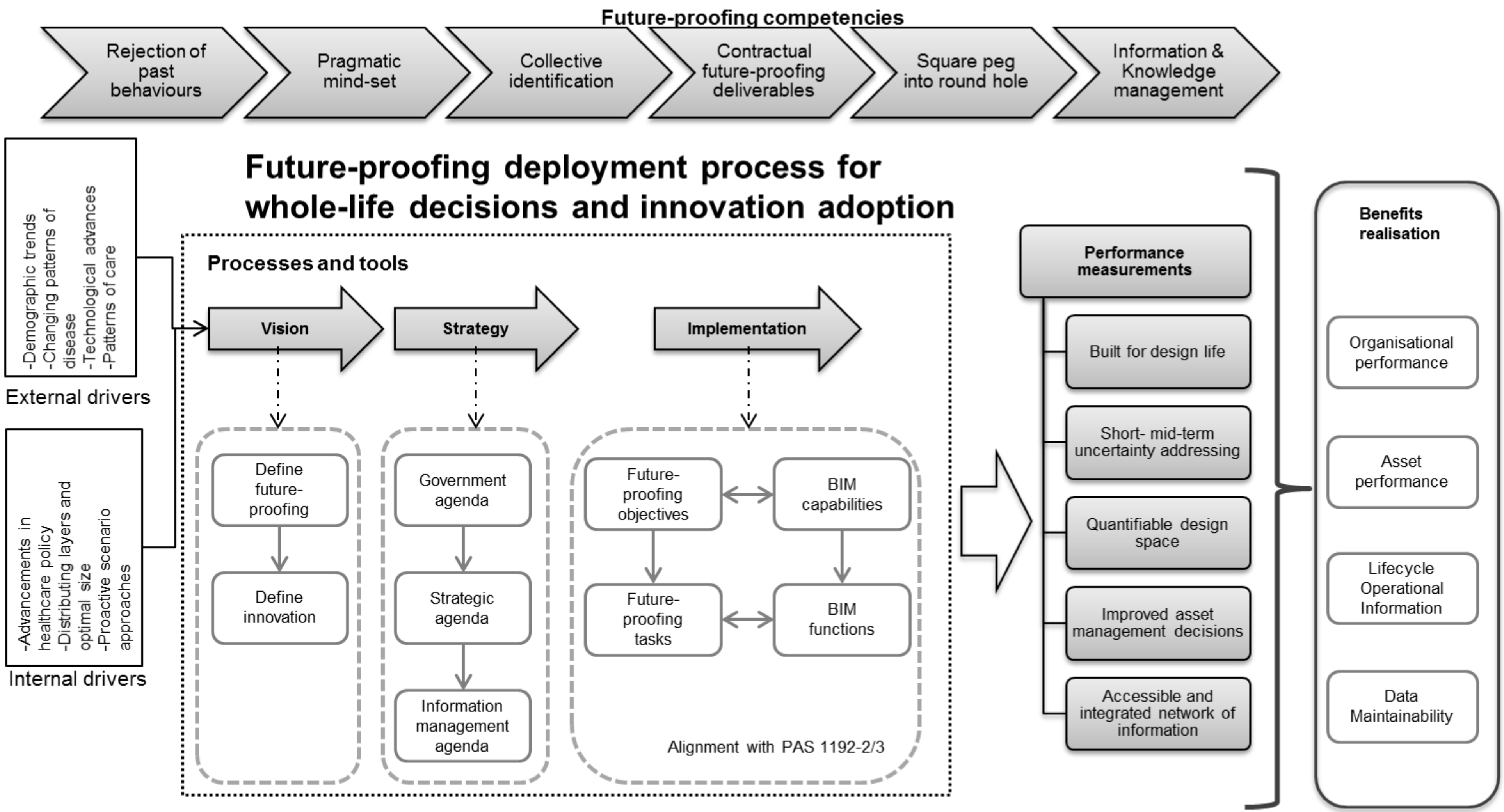


Figure 9-2: Future-proofing deployment at organisational level

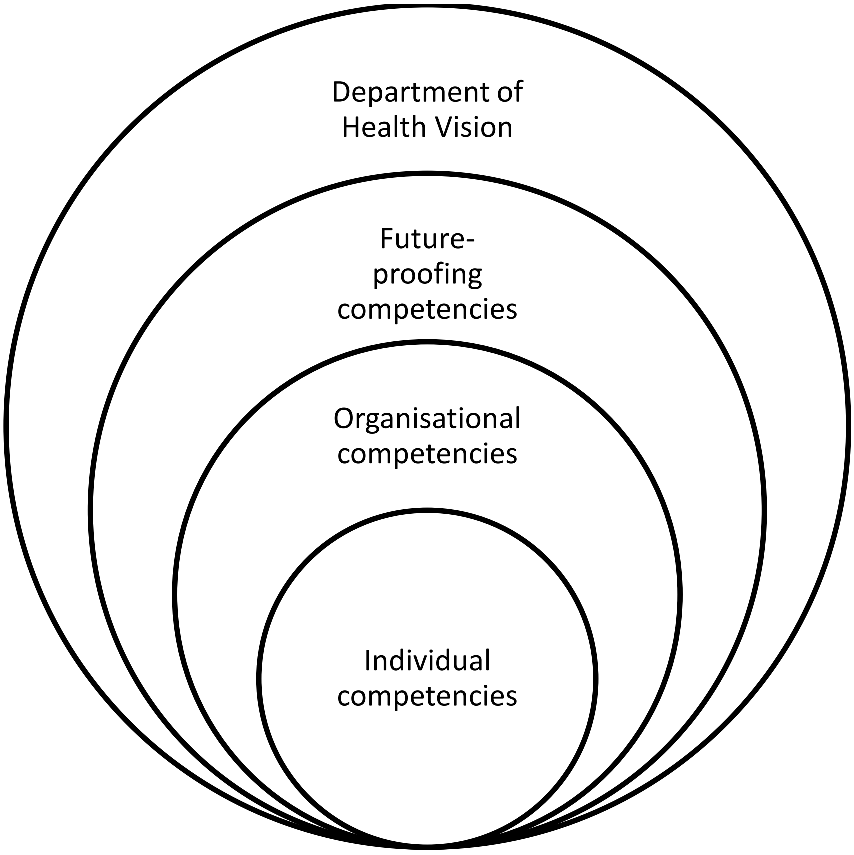


Figure 9-3: Hierarchy of competencies in an organisation

Below the future-proofing competencies are described:

Rejection of past behaviours: The interviewees described issues in whole-life decision-making regarding FP associated with negative behaviour. Future-proofing was referred by most interviewees as something they do superficially. After analysing the interviewees responses it was concluded that decisions about the future of the asset were affected by having 'false pre-conceived' past behaviours (Albarracin et al., 2000). These perceptions influence subsequent beliefs about future-proofing the investment. In order for an organisation to be able to provide meaningful and not superficial future-proof solutions there needs a change in behaviour regarding the importance of future-proofing.

Pragmatic mind-set: The term pragmatic was introduced by the interviewees to describe that the organisation should aim in developing assets that have the capability of being protected by future changes with a relatively low increase of capital cost. In addition, there seems to be a positive correlation between FP and patient outcome and this is capture in the following quote: *"I think we are being pragmatic. It would have been better to save perhaps 5% rather than 10% and have that flexibility and a better patient outcome than to not have flexibility and not have patient outcome and save 10% of the overall cost"* (I-4).

Collective identification: Within a healthcare environment the team consists of actors with various knowledge and expertise which makes the team multi-disciplinary in its nature. Every team member was found to have different set of goals that do not necessarily meet each other's. To ensure common goals are set in this setting, it is important that one organisational competency should be about increasing communication across the stakeholders responsible for making strategic decisions. Strategic decisions are *"steps in an overall process designed to move the organisation further toward a goal or set of goals"* (Bateman & Zeihaml, 1989) and the findings suggest that the goal for an organisation is in achieving cost reduction in relation to a time frame beyond that of the project's. Both issues can be associated with the actors (stakeholders and client) having 'low collective identification' (Van Der Vegt & Bunderson, 2005). Furthermore, Vegt and Bunderson suggested that *"the interaction between expertise diversity and collective team identification will be positively associated with team learning behaviour, and that team learning behaviour, in turn, will enhance overall team effectiveness by promoting continuous process improvement"*.

Future-proofing deliverables: The organisation should ensure that on every project and scheme no matter how small or big in scale, deliverables that are fit for use are ensured. There needs to be a formal process that documents the required deliverables. As such these deliverables need to be outlined in the Employers Information Requirements (EIR) document and the BIM Execution Plans (BEP). It is recognised that for smaller in scale projects, there not need to be an EIR and/or BEP of the same complexity and detail to a large in scale project, and the guidance documents can be scalable to the project's needs (i.e. a one page BEP should be sufficient for a small contract). However, it is also important to consider that a project can also be big in scale in terms of costs by can also have low complexity (i.e. only the replacement of all doors across a series of hospitals are contracted to a contractor). Similarly, a small in scale project might have great complexity and therefore detailed documentation would be sufficient. The above are summarised in Figure 9-4.

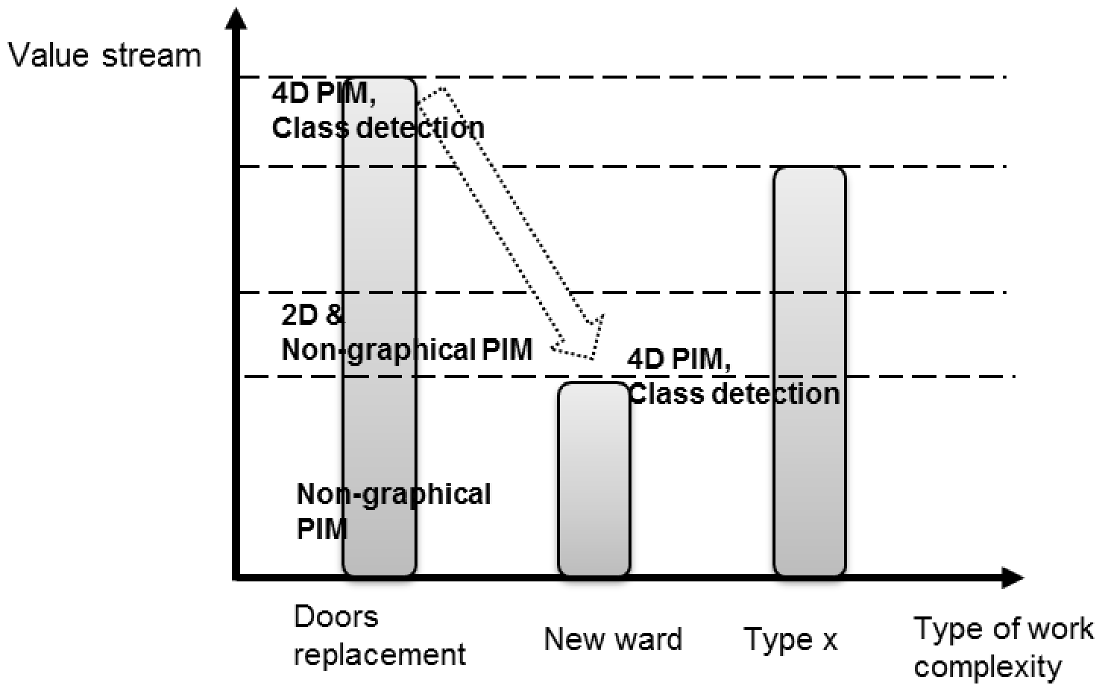


Figure 9-4: Scope deliverables against value stream and work complexity

With regards to the context of the deliverables, this needs to be coming from the Asset data strategy of the organisation. Deliverables that are within the scope of the strategy should be documented and captured. The organisation need of having a clear asset strategy, clearly communicated to the supply team. The list of assets that will development and be part of the deliverables package need to be described with attributes that will be valuable to a user that is going to use them in the near future. For example the colour of the wall may be unimportant but the suggested maintenance period of the elevator equipment will be important.

Controllable environment: The realisation that change is inevitable, should question whether mandatory changes will occur too late when future requirements demand it, - and thus having increased cost of changes - or ideally the organisations will build a 'platform of awareness' in which change will occur as Hamel and Prahalad suggested, in a 'controllable environment' (Hamel & Prahalad, 1996). This platform eventually should include a future-proofing 'insurance' and the 'fit for purpose' data that comes with it. As discussed in Chapter 7 the cost of design changes can be reduced in the MacLeamy curve if a BIM workflow is implemented early in the project and, in addition, the project is covered by a future-proof insurance.

Square peg into round hole: The intention of design technology within a Human-Computer-Interaction paradigm is to assist the design team to work more intelligently, efficiently, and effectively. BIM's aim is to provide transparency and flow of information to all members of the lifecycle, particularly the asset management team. However, the representation of information is identified as the medium that *"serves not only in terms to communicate some knowledge, but also to determine what is knowable"* (Kalay, 2006). In other words, a rich database that cannot be extracted in an automated and structured way is potentially a waste of data and obscureness of information. This influence by the technology is usually misunderstood or in many cases, undetected.

Based on this argument, Chastain et al. (2002) described the role of technology (medium) grounded in two paradigms. In the first one, technology is seen as a 'square peg in a round hole' while in the second paradigm is seen as a 'horseless carriage', similar to how the automobile was characterised in the beginning of the 20th century. The second paradigm refers to the obscureness of what new technology is capable to assist or for which situation is to be applied. The experts showed in general good understanding and awareness regarding the capabilities of BIM and thus the findings suggest that the construction industry has fallen in the first case (square peg into round hole). What this essentially means is that the medium (technology) that is used to communicate the product (information) needs to be in a format in which it will ensure that information will be available for the lifespan of the asset.

Information & Knowledge management: In Jung and Joo (2011), knowledge was identified as a factor that could drive the industry to the next level of BIM maturity. The importance of using BIM in consecutive projects in order to expand knowledge and share lessons was highlighted as well in Linderoth (2010). Essentially, these lessons learnt can be pulled from identifying BIM and FP KPIs for each project. The KPIs can be collected using project scorecards (Wyatt, 2004); where the project managers submit them on specified stages. As a note, it is not the scope of this study at this stage to identify the particular indicators for the identified process.

9.4 *Case study review: Performance outcomes*

This part of research has focused in identifying performance measures that could answer the question at an organisational level: 'How do we measure the performance of our future-proofing strategy?'. These measurements are essentially the outcome of the other two elements, namely the competencies and processes and tools (Figure 9-2). Performance measurement is *"the process of quantifying the efficiency and effectiveness of [an] action"* (Neely et al., 2005). A performance measure on the other hand is a metric that is used to quantify the efficiency and/or the effectiveness of an action. If a set of metrics is employed to measure efficiency and effectiveness of a series of actions, then this would be a performance measurement system (Neely et al., 2005).

Whilst performance measures quantify actions and find results, for 'benefits' or benefits management the case is different, perhaps because 'benefits' as a concept has often been replaced by stakeholders with project purpose or project goals (Cooke-Davies, 2002). In reality, the author distinguishes benefits management to the benefits of the project and highlights that:

- benefits are realised not only by the project management team, but also by the project sponsor or 'customer'; and
- project management success is realised at 'first order control' whilst project success involves a 'second order control'.

Hence benefits realisation can be described as a much 'finer method' to identify what has worked and how has the organisation benefited. The benefits of FP and BIM for an organisation have been presented in Chapter 8, thus in this section the performance measures are examined.

The DH has increased its focus over the years on measures around patients' experiences and had further *"provided a brief guide for measurement and feedback tools used to measure patients' experiences along with describing various methods available to gather patient feedback"* (Mahadkar et al., 2012). Furthermore, A

Performance Management tool has been created that gives an overview of performance management that help organisations to achieve improvement. As part of the exercise, balanced scorecards and KPIs are used to measure progress towards organisational goals (NHS, 2008). The measures are focusing on the following areas.

- Financial: *"to succeed financially, how should we appear to our stakeholders?"*
- Customer: "*to achieve our vision, how should we appear to the customers/patients/departments that we work with?"*
- Internal business processes: "*to satisfy our stakeholders and customers /patients/departments which internal processes must we excel at?"*
- Learning and growth*: "to achieve our vision, how will we sustain our ability to change and improve?"*

A performance measurement system is examined at three different levels (Neely et al., 2005):

- Measurement of the individual performance measures;
- Measurement of the performance measurement system as a whole; and
- Measurement of the performance measurement system and the environment within which it operates.

However, the scope of the proposed measures is with regards to future-proofing and innovation adoption; as such the measurement system is designed to address the scope of those two though it is recognised that an organisation would use more performance measurement systems (Figure 9-5).

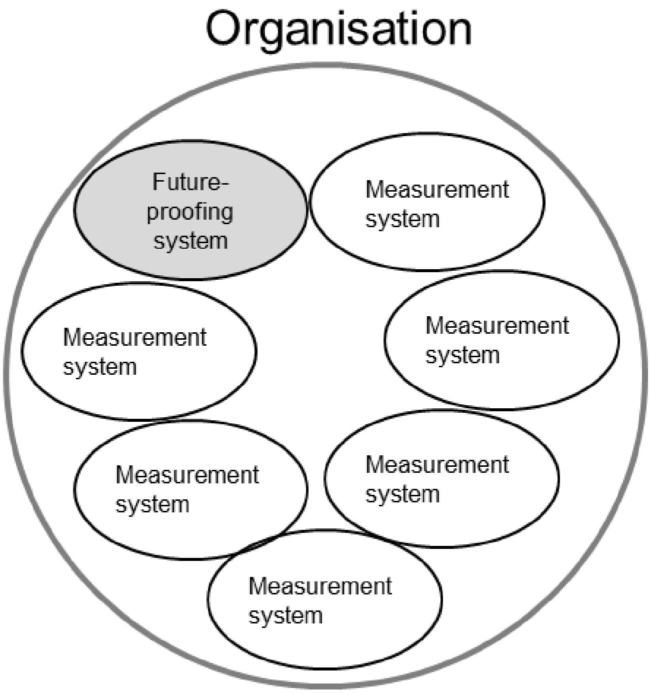


Figure 9-5: Multiple Performance measurement systems across the organisation

The following performance measures have been identified after investigating the processes and standards of the Owner Operator and from group interviews held with stakeholders involved in the organisation's BIM lifecycle processes:

Design for life: It was found that organisations will be able to measure the product (the asset) in terms of its effective design life. The organisation will further be aware about what assurances were made by the project team about its life expectancy, what considerations and assumptions were made and the identified risks. Plans for the future will need to be accommodated and be reflected in the asset.

Short- mid- term uncertainty: Uncertainty can be categorised into three categories, namely: short-, mid- and long-term. According to the findings an organisation should prioritise on the first two and the delivery plans should reflect that. The point of view made was that it is more realistic to deal with the first two rather than make investments to prevent something that might occur in more than 30 years where the future becomes more and more uncertain. Uncertainty was described as an increased deviation error when compared to time. The uncertainty curve is not linear but rather exponential, as factors such as medical technology and policy directives push the agenda into unknown areas; especially for long-term decisions.

Quantifiable design space: The organisation can also measure how the design space of solutions is narrowed by the applied tools and processes described in Chapter 8. Design space is a concept found in computational design research. It accounts on the designers' actions, development of strategies on explorations of the designers' actions and the discovery of computational structures to support exploration (Woodbury & Burrow, 2006). This measure is meant to translate qualitative concepts into quantitative proportions. As discussed in Chapter 6, elements of future-proofing are design standardisation and flexibility. This measurement can further showcase how these concepts are interconnected spatially with the asset, for example Zone 1 is 30% flexible and 10% standardised. Furthermore this can further be showed in a BIM process by including as metadata values into information exchange formats such as COBie or .csv files.

Improved asset management decisions: Decisions at this stage will become more informed. The organisation at this stage will have access to information that will allow it to make informed and justified decisions. Such decisions are supported by the ability to store information within a BIM process. This means that future scenarios and the impact of changes can be stored in the form of 'what if' scenarios within a BIM model centric database. Such capability will allow the business to observe how the investment is affected by a change that was scheduled during the early stages of the project.

More accessible and integrated network of information: From feasibility studies to the operational life of the asset, data is generated across all stages and information is derived that further communicates knowledge about the asset condition and history of the asset. This iteration further supports micro and macro management decisions. The asset receives constant feed of data from multiple streams and becomes essentially a live data base.

9.5 *Conceptual future-proofing approach*

The concept of FP within BIM at governance level was presented in detail in Chapter 7, whilst the tools and processes used for delivering a future-proof project was presented in Chapter 8. In summary, the competencies described in Section 9.3 are the *"building blocks which begin to address gaps around informed decision making* *for healthcare infrastructure planning"* (Mahadkar et al., 2012) and present the wider organisational view. The conceptual future-proofing approach covers the tools and processes to deliver a future-proof project using BIM. The approach is structured in the following three stages.

- *Vision*: the organisation defines what future-proofing means for the business, and informs the stakeholders and supply chain about the aspiration of the organisation to satisfy future-proofing conditions as well adoption of innovative technologies and processes.
- *Strategy*: the strategy involves the identifications of future-proofing considerations across three agendas, Government, Strategy and Information management agenda. Each agenda helps the business more explicitly define future-proofing and information management and further refine what both concepts mean to the business processes.
- *Implementation*: the last stage covers how to apply future-proofing and BIM strategies at project level. It identifies the synergies of PF and BIM across a project's lifecycle and showcases the strengths of using BIM in a FP framework.

The next step towards FP is for the organisation to do a 'first order control' and investigate the outcomes of such approach and what are the effects and benefits to the business. This was summarised in Section 9.4. Then, a 'second order control' takes place, where the organisation runs an exercise 'internally' towards benefits realisation, in which the evaluation of what was actually achieved indirectly by the business. The analysis discussed in Chapter 8 found that organisational performance, asset performance, lifecycle operational information and data maintainability are the benefits that are realised for the organisation that choses to include FP and BIM in their processes.

9.6 *Chapter Summary*

This chapter presents an enterprise deployment plan for whole-life solutions being future-proofed whilst being supported by the adoption of BIM processes. FP Competencies in healthcare organisations were presented and were further aligned to the organisational and individual competencies that act as the building blocks of the organisation's vision. At 'first order control' the organisation's management team identify performance outcomes to measure the effectiveness of deploying FP and BIM processes in their assets delivery plan. In the 'second order control', the organisation as a sponsor realises the benefits for using BIM and FP at enterprise level.

Chapter 10 Discussion

10.1 *Introduction*

A summary of the findings from the previous chapters and provides a critical review of the literature are presented in this chapter. The findings of all employed research methods are collated together in this chapter and are further enhanced with relevant and contradicting literature. The chapter is structured in a way that will help the reader explore the meaning of FP both in theoretical terms – using elements of design theory - and practice terms – work breakdown structure of objectives and tasks across the project lifecycle. The chapter presents the findings in a three-fold context: client-focus, delivery-focus and BIM-focus so that it establishes a conceptual framework that can be used in the empirical research analysis and synthesis.

10.2 *Delivery-focus findings*

The following sections elaborate on the findings of this research that emerged from the Survey data (Chapter 6) and discussed in Section 10.2.1 and the IPA analysis (Chapter 8) and the findings are discussed in Section 10.2.2. These findings are focusing and contributing to the delivery practice.

10.2.1 **Positioning the concepts of flexibility and standardisation in design for FP**

The discussion of this section presents the theoretical underpinnings regarding the contribution of the concepts of flexibility and standardisation to FP. Edwards and Harrison (1999) highlighted that adoption of inflexible design scenarios will result in future conflictions. This means, design options are not incorporated to allow flexibility. Additionally, the DH reports that the focus is no more on structures and processes (DH, 2010). It is not arguable that forecasting is essential to design. It is though important to support design with evidence. Graham P. (2005) summarised, *"a sustainable building is not one that must last forever, but one that can easily adapt to change".* In order to enforce and promote better design solutions under realistic events, the need for flexibility as a design solution is becoming a necessity (Olsson & Hansen, 2010). The findings in Chapter 6 and the Survey that was conducted suggested that design standardisation can be used in conjunction with flexibility strategies and the outcome would be change-readiness ingrained in design delivery.

However, this part of the study and thus the findings were treated as exploratory due to there was diversity in the responses and the sample size was small. The study tested the hypothesis whether there is integration between flexibility and standardisation and the results were above average. It was recognised that each strategy has its weaknesses and strengths but when in combination, it can be said that they can bring change-readiness in design. Below, elements of design theory are employed to clarify and position the two concepts of standardisation and flexibility as they emerge in the concept of FP.

Design space is a concept found in computational design research. It accounts on the designers' actions, development of strategies on explorations of the designers' actions and the discovery of computational structures to support exploration (Woodbury & Burrow, 2006). Simon (1996) described design as a problem itself that requires answers. According to Newell (1979:5) *"a problem space consists of a set of symbolic structures (the states of the space) and a set of operators over the space"*. Additionally, there is no linear process from problem to solution (Lawson, 2006) and since there is more than one problem spaces (Newell, 1979) design seems to be the only means to drive to "satisficing" solutions (Simon, 1996). Krishnamurti (2006) described design space as the sum of the problem space, solution space and design problem.

The problem space is shaped only by the potential solutions that satisfy the established requirements. The solution space on the other hand is formed by all potential solutions for a given design problem. The design process *"consists of methods used to develop candidate solutions from requirements"* (Gane, 2011). A design problem cannot be solved from a single best solution, but from a set of satisfactory solutions. Hence, the designer should expect to define or redefine or change the design problem as it is being shaped through time while exploring the design space of possible solutions (Cross, 2001).

Engineering design theory can employ optimization methods to analyse and solve a design problem. Simon (1996) described the logic of optimization methods as follows:

the process can be divided into two environments; the inner environment of the design problem represents the alternatives, a set of variables that require an understanding of the design and operation of the system. The outer environment can be described as a set of parameters derived from systems' requirements (Simon, 1996) or a set of probability distribution, the key drivers (de Neufville & Scholtes, 2011). The objectives for adaptation from outer to inner environment are defined by a set of variables and parameters which are supplement by a set of constraints. The optimization problem is solved by finding *“a set of values of the command variables, compatible with the constraints that maximize the utility function for the given values of the parameters”* (Simon, 1996).

The design process consists of procedures used to develop candidate solutions from requirements. Akin (2001) analysed the design process as the sum of the design knowledge and design strategy, where strategy refers to the search the designer carries out and knowledge stands for all the means the designer uses to represent the multiplicity she needs and finds useful. Such representations could be the designer's actions, processes, design states etc.

Moreover, Fricke (1996) categorised strategy into function oriented, where the designer focuses on one problem area, solving it from abstract to concrete level and then continues to seek answers to the following problems, and step-wise process-oriented, where the designer considers all the relevant problem areas and holds a more abstract level of solutions before becomes more concrete. Ahmad et al. (2014) suggested that design knowledge and thus "satisficing" healthcare design solutions will emerge from the application of flexibility, design standardisation and the information management abilities of BIM. The above are summarised in Figure 10-1 and in Appendix B.

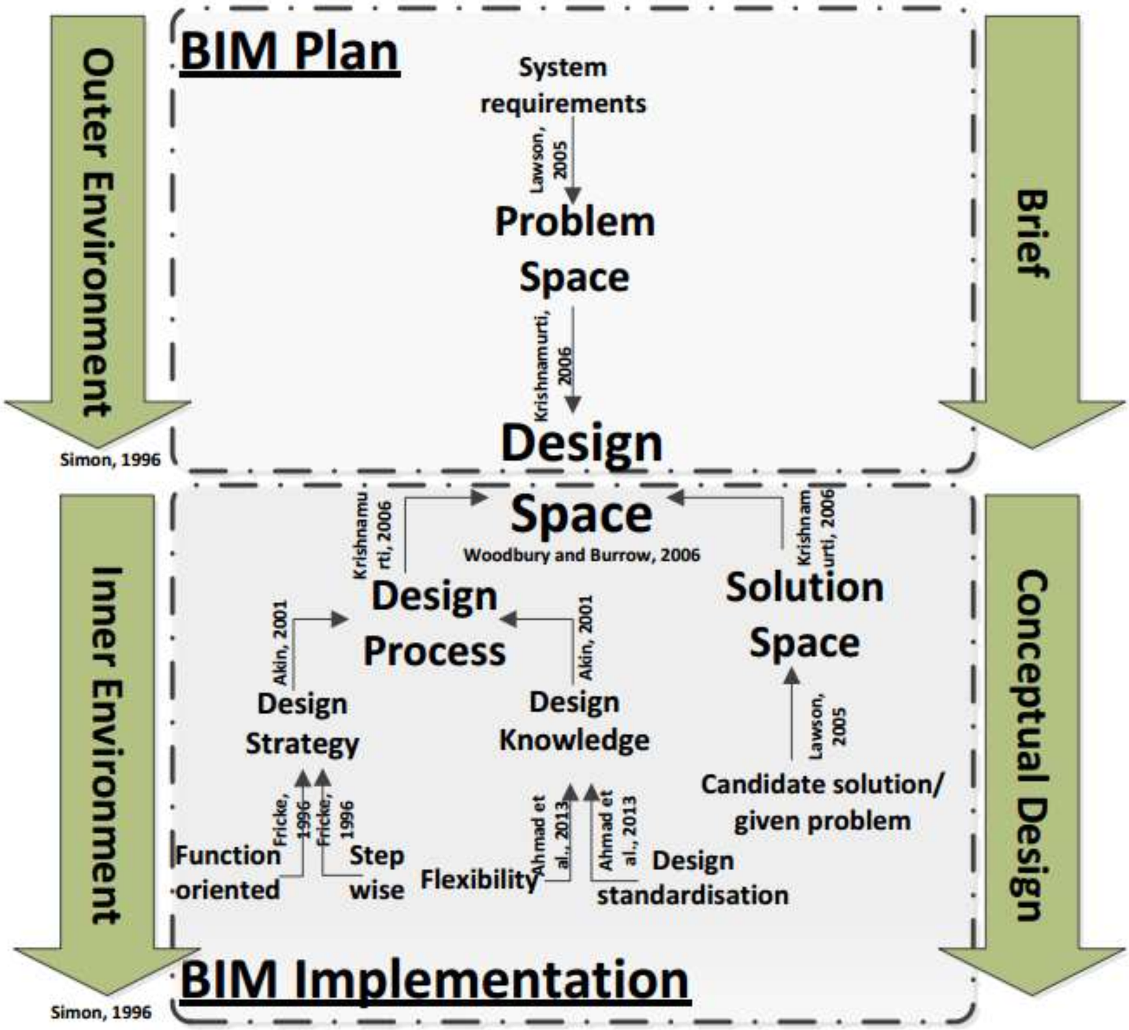


Figure 10-1: Future-proof healthcare design by narrowing the design space of solutions.[12]

10.2.2 **Objectives and tasks for delivering future-proof projects**

The findings from Chapter 8 are discussed in greater detail. Obsolete assets are characterised by their single-use design perspective. Beliefs such as applying the best solution so that no change will be required in the future has as a result of fixed construction developments (Yang 2006; Gann 1996; Iselin 1993). From a design perspective, the question is on what is most likely to occur. The Designer is expected to be the 'technological forecaster' or foresight analyst (Finch, 2009). The issue of constructing assets that will be capable to adapt in time due to changing needs is not unfamiliar. Kendall (1999) described that such kind of assets should be stable, but 'open' to receive new technologies and be able to follow the on-going organisational

[12] *For more details please see Appendix B*

changes and the various life styles and trends. Time is an important factor regarding design and construction. If the stakeholders manage to do both acts for present and future use, then the whole concept becomes sustainable (Kendall, 1999).

Future-proof design and delivery can deliver more efficient workforce by supporting good communications and avoiding interruptions in order to reduce errors (Francis, 2010). It should not be given the wrong idea that one can predict future changes (Brand, 1995), but rather to try and construct a ‘platform of awareness’ where the asset can better be used to inform design decisions.

The findings in Chapter 8 showcased a first level (objectives) and second level (tasks) process of implementing FP strategies. The objectives that emerged across the main project stages are:

P-I: Future-proofing brief setting: Future-proofing needs to be brought in to the discussion at the very early stages and be included clearly in the business case. The clients should clarify their FP goals to the design consultants and contractors.

P-II: Investment and Portfolio agenda: According to the interviewees, FP should not only consider how spaces could be adaptable to operational changes; it should also identify investment opportunities within the facility itself and across the wider location of the building.

P-III: Adaptive-friendly procurement method: The procurement method should allow the core principles of FP to be implemented, and as such it is essential to adopt and merge some of the unique benefits that have been identified in most of the existing procurement methods (i.e. PFI’s contractor’s involvement throughout project’s lifespan, P21+ introduction of standardised generic components etc).

P-IV: Identification of flexibility: The core principles of FP are *flexibility* and *adaptability*. These two need to be identified and discussed as early as possible and should be defined in terms of future user behaviours and needs.

P-V: Responsiveness of government strategic goals: Due to the criticality of these projects, the supply side and the clients should agree that going beyond the standards (i.e. the Building Regulations) is sensible to ensure sustained quality delivery to patients and staff.

P-VI: Healthcare scenario factors: Healthcare experts reported that testing room adjacencies; documenting activity projections; commissioning of services; patients flow; and room usage data etc. is essential to design successful healthcare projects.

P-VII: Standardisation agenda: The interviewees believed that standardisation should also drive towards corporate identity, thus ensuring that patients will receive a consistent standard of quality of services.

P-VIII: Use of resources: When designing healthcare facilities, the designers need to consider the distribution of resources across the health service and consider applied changes to the existing system and how these will reflect on the space that is provided.

P-IX: Whole-life assessment: According to the respondents, flexibility provision depends on cost, thus it should be considered what the effect of flexibility will be in terms of whole-life cost evaluation when it is introduced in the design.

P-X: Knowledge systems: Important factors such as criticality and conditional levels of equipment (mainly for maintenance) are considered. The interviewees suggested that it is important to collect more sophisticated health data about trends, e.g. data specific to the region's future needs with regards to health services.

P-XI: Healing environment: In terms of FP, the supply chain members need to note in their plans that any future scenarios should not hinder considerations of such spaces.

Design

When proceeding in this phase, all planning objectives become visual representations and richer documentation should be produced to allow easier communication of FP. This phase and the subsequent one reflect this notion:

D-I: Demonstrating change-readiness of design: The design team focuses on the design implementation of accommodating the changes the asset will undergo throughout its lifespan.

D-II: Demonstration of maintenance plans: The interviewees who are involved in the operation phase emphasised the importance of maintenance strategies in asset management, and if not planned with care maintenance costs can be up to 10 times higher than construction cost.

D-III: Demonstration of flexibility plans: A clear demonstration of how flexibility is introduced within the asset is required to capture the strategy that was decided in the previous Planning phase.

D-IV: Generic spaces and elements: Generic spaces (rather than bespoke rooms) that have built-in agility and can easily and cheaply be modified into most types of NHS rooms were suggested by the interviewees.

D-V: Demonstration of disruption plans: This objective is to ensure that future upgrading will be done with minimum disruption of uses. Disruption plans refer to the physical elements of the asset.

Construction

In this phase, FP takes on a physical manifestation. The final product is still underway, thus it is still necessary to communicate any FP aspects to the construction stakeholders.

CO-I: Publication and application of FP strategy on site: FP aspects might not be obvious in a design drawing, or any necessary on-site changes need to be checked that they do not intersect with the FP requirements.

CO-II: FP of working conditions: FP does not only respond to organisational changes. On-site construction conditions should also be future-proofed in the same way changes are addressed within the organisation.

Operation

The final phase of the project works as an evaluation for the effectiveness and efficiency of FP. The end users have an active role and note which practices work best and which do not in order to suggest improvements to the FP strategy. The strategy must continue to evolve during the operation phase in the same way other frameworks do (i.e. Soft Landings).

O-I: Awareness of FP strategy: The end users need to be aware of the FP strategy. All the information that was produced in the previous phases should be handed over and demonstrated to the end users.

O-II: Feedback from future-proof project: The end users (building occupants) have an active role regarding the building's lifespan in terms of evaluating its performance and effectiveness in its ability to adapt to the forthcoming needs.

O-III: Reuse of components and materials: In case of demolition, the strategy should ensure as many as possible components and materials can be reused in a new project. In addition, lessons learnt should be drawn and later used as evidence to inform future FP strategies.

Development of objectives aligned to implementation tasks positioned in project delivery for lifecycle future-proof decisions. The objectives span across the lifespan of a project/asset, from concept to operation. The objectives are communicated through a series of BIM capabilities. The synergy of FP and BIM is further elaborated from the identification of 30 interactions that emerge between the synergy of those two.

10.3 *Procurer-focus findings*

The following sections elaborate more on the findings of this research that emerged from the Case study data (Chapter 7) and the triangulation analysis (Chapter 9) and are contributing to help clients better manage and procure FP.

10.3.1 Governance issues for future-proofing development – a client perspective

Questions arise around how we plan and manage assets that are able to accommodate future demands. It becomes detrimental to realise that there are limits in accurate forecasting. The findings of the Case study as presented in Chapter 7 identified the agendas at strategic level that FP governance considerations need to take place. The concept of FP took a holistic stance and thus the governance agendas expand from government, strategic and implementation considerations. More specifically, a series of government actions were proposed, followed by types of decisions at enterprise level the clients and their supply partners need to make and concluded with high level implementation process strategies and support by IT. Namely the content of the aforementioned agendas is:

- *Government agenda*: this agenda includes actions for both FP and BIM and works as a controlling and supporting mechanism that ensures Clients and the supply chain are working together for the delivery of future-proof assets.

- *Strategic management agenda*: this agenda includes decisions the Clients are taking with the support of the supply chain. These decisions are about obtaining a change-ready asset with the best possible flexibility incorporated throughout its lifespan.

- *Information management agenda*: the last agenda includes processes and support from technology the supply chain needs to adopt in order to deliver the goals and aspirations set by their Clients.

It was also highlighted that Owners that deploy future-proofing strategies and ‘fit for purpose’ asset data across an enterprise model will benefit with having less costs of design changes due to future-proofing being an insurance measure ingrained in the asset. Major savings can be accomplished by setting the right ‘fit for purpose’ data in place and in accessible format. This will mean that asset management teams will be able to use and make informed decisions regarding changes that take place during the life of the asset. These informed decisions will originate from the data that comes with the delivered asset.

10.3.2 **Future-proofing competencies for healthcare organisations**

In this section the findings of Chapter 9 are discussed. In the context of informed decision making for healthcare infrastructure planning, competencies are helping an organisation address identified gaps around this area. Future-proofing competencies were position hierarchically above organisational and individual competencies. The justification for this is that a FP competency can further feed into organisational competencies which will steer the organisation towards its vision. The competencies are:

Rejection of past behaviours: Future-proofing was referred by most interviewees as something they do superficially. After analysing the interviewees responses it was concluded that decisions about the future of the asset were affected by having 'false pre-conceived' past behaviours (Albarracin et al., 2000). In order for an organisation to be able to provide meaningful and not superficial future-proof solutions there needs a change in behaviour regarding the importance of future-proofing.

Pragmatic mind-set: The term pragmatic was introduced by the interviewees to describe that the organisation should aim in developing assets that have the capability of being protected by future changes with a relatively low increase of capital cost. In addition there seems to be a positive correlation between FP and patient outcome.

Collective identification: Within a healthcare environment the team consists of actors with various knowledge and expertise which makes the team multi-disciplinary in its nature. Every team member was found to have different set of goals that do not necessarily meet each other's. To ensure common goals are set in this setting, it is important that one organisational competency should be about increasing communication across the stakeholders responsible for making strategic decisions.

Future-proofing deliverables: The organisation should ensure that on every project and scheme no matter how small or big in scale, deliverables that are fit for use are ensured. There needs to be a formal process that documents the required deliverables. As such these deliverables need to be outlined in the Employers Information Requirements (EIR) document and BIM Execution Plans (BEP). It is recognised that for smaller in scale projects, there not need to be an EIR and/or BEP of the same complexity and detail to a large in scale project, and the guidance documents can be scalable to the project's needs (for instance a one page BEP should be sufficient for a small contract). However, it is also important to consider that a project can also be big in scale in terms of costs by can also have low complexity (i.e. only the replacement of all doors across a series of hospitals are contracted to a contractor). Similarly, a small in scale project might have great complexity and therefore detailed documentation would be sufficient.

Controllable environment: The realisation that change is inevitable, should question whether mandatory changes will occur too late when future requirements demand it, - and thus having increased cost of changes - or ideally the organisations will build a 'platform of awareness' in which change will occur as Hamel and Prahalad suggested, in a 'controllable environment' (Hamel & Prahalad, 1996). This platform eventually should include a future-proofing 'insurance' and the 'fit for purpose' data that comes with it.

Square peg into round hole: The intention of design technology within a Human-Computer-Interaction paradigm is to assist the design team to work more intelligently, efficiently, and effectively. BIM's aim is to provide transparency and flow of information to all members of the lifecycle, particularly the asset management team. However, the representation of information is identified as the medium that *"serves not only in terms to communicate some knowledge, but also to determine what is knowable"* (Kalay, 2006). In other words, a rich database that cannot be extracted in an automated and structured way is potentially a waste of data and obscureness of information. This influence by the technology is usually misunderstood or in many cases, undetected.

Information & Knowledge management: In literature, knowledge was identified as a factor that could drive the industry to the next level of BIM maturity. Essentially, these lessons learnt can be pulled from identifying BIM and FP KPIs for each project. The KPIs can be collected using project scorecards (Wyatt, 2004); where the project managers submit them on specified stages. As a note, it is not the scope of this study at this stage to identify the particular indicators for the identified process.

10.3.3 Performance outcomes within a FP and BIM context

In this section the findings of Chapter 9 are discussed. Innovative processes such as BIM has the capability to affect the core processes and products of design and construction and affect all the professions evolved in throughout the project lifecycle (AIA 2007; CIC 2013; Eastman, et al. 2011). BIM planning and implementation of a

BIM model as analysed and documented by researches and governmental organisations (CICRG, 2010) have presented a change of process; a different perspective of analysis of the problem and the potential of a bigger perspective or a higher design space potential of possible solutions (Gane, 2011).

The following performance outcomes (Chapter 9) have emerged from the triangulation analysis and have been developed to help healthcare organisations identify how to measure the performance of their FP strategies:

Design for life: Organisations will be able to measure the product (the asset) in terms of its effective design life. The organisation will further be aware about what assurances were made by the project team about its life expectancy, what considerations and assumptions were made and the identified risks. Plans for the future will need to be accommodated and be reflected in the asset.

Short- and mid- term uncertainty: Uncertainty can be categorised into three categories, namely: short-, mid- and long-term. According to the findings an organisation should prioritise on the first two and the delivery plans should reflect that. The point of view that was made was that it is more realistic to deal with the first two rather than make investments to prevent something that might occur in more than 30 years where the future becomes more and more uncertain. Uncertainty was described as an increased deviation error when compared to time. The uncertainty curve is not linear but rather exponential, as factors such as medical technology and policy directives push the agenda into unknown areas; especially for long-term decisions.

Quantifiable design space: The organisation can also measure how the design space of solutions is narrowed by the applied tools and processes described in Chapter 8. This measure is meant to translate qualitative concepts into quantitative proportions. This measurement can further showcase how the elements of FP, for instance flexibility and standardisation are interconnected spatially with the asset. Furthermore this can further be showed in a BIM process by simply include these metadata values into information exchange formats such as COBie.

Improved asset management decisions: Decisions at this stage will become more informed, as the organisation of this stage will have access to information that will allow it to make informed and justified decisions. Such decisions are supported by the ability to store information within a BIM process (Demian & Walters, 2014). This means that future scenarios and the impact of changes can be stored in the form of 'what if' scenarios within a BIM tool. Such capability will allow the business to observe how the investment is affected by a change that was scheduled during the early stages of the project.

More accessible and integrated network of information: From feasibility studies to the operational life of the asset, data is generated across all stages and information is derived that further communicates knowledge about the asset condition and history of the asset. This iteration further supports micro and macro management decisions. The asset receives constant feed of data from multiple streams and becomes essentially a live data base.

10.3.4 **Benefits realisation for Healthcare Organisations**

The benefits of FP and BIM for an organisation have been presented in more detail in Chapter 8. In order for an enterprise to remain competitive in an increasingly dynamic market, it has to become more agile in the performance of its core asset function. Enterprise asset strategies should be more co-operative with organisational changes in order to for space to be used more effectively (Thomson et al., 1998). Whilst performance measures quantify actions and find results, for 'benefits' or benefits management the case is different, perhaps because 'benefits' as a concept has often been replaced by stakeholders with project purpose or project goals (Cooke-Davies, 2002). In reality, the author distinguishes benefits management to the benefits of the project and highlights that:

- benefits realisation are realised not only by the project management team, but also by the project sponsor or 'customer'; and
- project management success is realised at 'first order control' whilst project success (benefits) involves a 'second order control'.

With this in mind, benefits realisation is a much 'finer method' to identify what has worked and how has the organisation benefited. For benefits realisation in the context of BIM and FP, after distilling the 30 interactions between the FP objectives and the BIM capabilities, it can be concluded that whole-life communication is the most relevant feature of BIM for implementing FP and thus FP objectives can be clearly communicated within the project's lifespan. The stakeholders could better associate FP objectives to organisational and building performance through BIM. In addition, BIM supports the development of lifecycle operation information via becoming a communication platform and thus ensuring 'data maintainability'.

10.4 *BIM-focus findings*

The following sections elaborate more on the findings of this research that emerged from the IPA analysis (Chapter 8) and the Case study (Chapter 7) and offer a meta-critique of how BIM benefits the industry and contributes to FP. As is evident from the previous sections, elements of BIM are embedded in both the procurer-focus and the delivery-focus findings which is not surprising, given that BIM is not an out of the box- detached solution but a way of delivering and managing a project/asset.

10.4.1 **BIM capabilities for conceptualising future-proofing decisions**

It is a challenging task to establish the impact of information technology in the construction industry. It is necessary to document an informed view of opportunities in need of further development. Technological revolutions and social revolutions are closely related (Kalay, 2006). It is understandable that new technology stimulates the society to use new tools, methods and techniques for implementing a project. This deployment, affects the society itself economically, culturally, politically as well as in other ways (Kalay, 2006).

In order to do BIM the notion is that traditional practices will eventually be replaced by new ones. For example in the RIBA (2012) paper it was stated that *"to move smoothly from one BIM maturity level to another there is a need to adopt industry-wide (rather than professional or practice-exclusive) processes, and consider ways to build and manage successful project teams and contribute to the debate on the best forms of procurement that will truly encourage collaboration and innovation, and drive waste and efficiency out of the construction industry"*. Moreover, it was highlighted that *"the BIM Overlay to the RIBA Outline Plan of Work"* is a preparation paper towards the next generation of processes that the UK Government is planning to implement (Cabinet Office, 2011). Additionally, Succar et al. (2012) stated that *"the implementation of any new technology is fraught with challenges and BIM is no exception".* BIM is changing the business process (Livingston, 2007) and that means that a change management process is undergone in the construction industry and that involves changes in strategy, delivery and the organisation itself. The industry is starting to realise that BIM is not only used during design or for sequencing but that its capabilities expand throughout the lifecycle.

BIM capabilities are qualities found in the BIM process, not necessarily the tools (e.g. BIM Execution Plans). These capabilities were further distilled and are only relevant to conceptualising FP. In summary, these have been identified as:

Flexible data: flexibility in this instance means that the data can be used by multiple teams across the project and throughout the asset's lifespan for multiple purposes. To ensure data flexibility, there needs to be a standard procedure for information exchange and systems interoperability, which a BIM process is trying to address.

Optioneering capabilities: Optioneering studies are becoming more easily implemented within a BIM process framework. Information has become easily accessible and this is further supported by technology advancements. BIM offers not only the possibility of running many 'what-if' scenarios to choose the best possible solution based on the Clients' requirements but it can also be used for evaluating possibilities regarding the scenarios an asset can accommodate post-handover.

Project evaluation: BIM is also becoming a quality assurance process for evaluating models and validating data input. In terms of FP, BIM can be used for quantifying how future-proof an asset can be, identify resilient-sensitive areas and inform decision making.

Standardised object catalogues: Just like the automotive industry, it is now possible to have libraries of components that can be re-used from project to project, saving time and resources. These components and their properties can to be backed up with evidence i.e. performance, durability, maintenance conditions etc. to better support future-proofing decisions.

Whole-life costing: essentially this is the main purpose of moving towards BIM process delivery. The PAS 1192-2 and the PAS 1192-3 processes / guidelines outline how a CAPEX model will be used to support OPEX purposes. With BIM it is now possible to have whole-life cost models in place and evaluate future scenarios about the asset in question.

Whole-life communication: Communication of requirements, rich-based complex databases, early data that can be useful for the Asset management teams are only a few examples that make communication the strongest capability of BIM. Communication is the key for effective delivery of change-ready assets and volumetric design, software agnostic exchange packages (i.e. COBie) and visualisations are some of the examples of this capability.

These capabilities where then further connected into 30 interactions that emerged between the framework of FP and BIM processes and are presented in greater detail in Table 8-4 to Table 8-9 (please see full discussion in Chapter 8 and also Appendix D and Appendix E). A summary of the 30 interactions of BIM is given in Table 10-1to Table 10-6.

Table 10-1: Flexible data interactions with FP

Interactions
Gradual data - Data production aligned to each phase
Expanded use of BIM to non-design tasks
Adaptable data for various actors
Maintained data availability
Online live databases linked to the model

Table 10-2: Optioneering capabilities interactions with FP

Interactions
Collaborative 'what if' scenarios
Design integrity
Multi-purpose scenarios
Quicker check of design alternatives

Table 10-3: Project evaluation interactions with FP

Interactions
Benchmarks and recommendations
Comparison of existing condition against future requirements

Quantification of FP

Table 10-4: Standardised space catalogues interactions with FP

Interactions
Have something to work with – not starting from scratch
Increases familiarity of staff with workspace
Minimises the need for disruptive stakeholder engagement
Reduction of clinical errors
Supply chain cost reduction
Repeatable design is linked to evidence and experience
Specifications become default and automated input

Table 10-5: Whole-life communication interactions with FP

Interactions
Virtual representation and roadmap of FP
Operational knowledge
Communication of working specifications
Fully multidisciplinary integrated model
Non-physical presence for design reviews and workshops
Standardised information process flows
Volumetric process-understandable by non-experts
Visual precaution tool

Table 10-6: Whole-life costing interactions with FP

Interactions
Classes minimisation-cost savings
Cheaper check of alternative solutions
Reducing the cost of resources

The below section reflects on the application of BIM in projects where its value was questionable. Bynum et al. (2012) found that BIM has a stronger application in project coordination and visualisation than it has for sustainability. Others found that the representations offered by BIM do not necessarily make the exploration of design solution space more effective or efficient, and that AEC professionals find solutions through what some authors referred to as 'messy talk' (Dossick & Neff, 2011). BIM was found not to foster collaboration across different companies, in contrast to increasing the collaboration among project members (Dossick & Neff, 2010). Non-technical organisational maturity was found to be more important than technological maturity in companies interested in adopting BIM. Researchers suggest that non-technical readiness should be addressed before technological readiness (Won et al., 2013).

Interoperability issues are recognised and have been documented in a number of studies (Demian & Walters 2014; Korpela, et al. 2015; Grilo & Jardim-Goncalves

2010; Gallaher, et al. 2004). Manning and Messner (2008) looked at healthcare case studies and found data transfer bottlenecks and a later study found that the industry had not yet found a way to resolve interoperability issues (Bynum et al., 2012). Return on investment (ROI) issues have been discussed widely in literature (Russell, et al. 2014; Giel & Issa 2013; Becerik-Gerber & Rice 2010), and Giel (2009) highlighted that ROI is greater as the complexity of the project increases, thus making it more difficult to justify the need for BIM for smaller scale projects.

10.5 *Chapter Summary*

Selective critical literature was used to challenge the findings of this research and further support the work that was done and streamline it with other research. Furthermore, the findings of this study were presented according to the focus they are addressing, i.e. procurer-focus, delivery-focus and BIM-focus and were further supported with findings from literature. The finding also suggested that elements of BIM are embedded into the more traditional procurer and delivery activities and plans. This comes to no surprise given that BIM is not a detached solution but a way of delivering and managing a project/asset.

Chapter 11 Conclusions

11.1 *Introduction*

This research studies the phenomenon of future-proofing (FP) and how this is deployed in healthcare environments in terms of a) project delivery and b) organisational adoption for owner operators at an enterprise level. It furthermore investigates the role of BIM with regards to a) and b). Two research questions have been expressed in Section 1.3, and through a set of research objectives, this study attempted to find answers based on the experiences of industry experts in the field of construction and BIM. The following sections present the conclusions of this study, the limitations, future recommendations and a summary of outputs.

11.2 *Have the research questions been addressed?*

In this section, the research questions set in Chapter 1 are revisited and a response based on the findings is given.

Research question 1: How can the supply chain (consultants and contractors) deliver future-proof solutions *and* how can owner operators be prepared in managing future-proof healthcare assets?

The first question has been addressed through the development of a holistic future-proof approach where conceptual constructs emerged from a series of research methods (Survey, IPA, Case study) that have been deployed in an interpretivist framework (see Figure 5-5, page 65).

A top-bottom approach was adopted to present the solution process. Initially, a bottom-up approach was investigated, but it was soon realised that FP is a concept that it cannot be addressed by only re-engineering design strategies or providing solutions that rely solely on the power of IT tools.

Clients tend to focus on a single preferred option (Chapter 7) and neglect values such as flexibility, design life and whole-life cost. This research identified the internal and external factors that lead to obsolete healthcare assets (Chapter 2) and provided a change management model for deploying FP into healthcare organisations (Chapter 9). As part of the deployment plan, FP organisational competencies have been identified and presented in detail in Chapter 9.

Next, processes and tools have been identified that will further support a change management model. These have been broken down further into strategy (governance) (Chapter 7) and implementation (delivery) (Chapter 8). Governance agendas for owner operators regarding the concept of FP have been identified and presented in detail in Chapter 7.

With regards to the first part of the question, for the implementation and delivery of FP in construction projects; a series of FP objectives and tasks that can be embedded in a Work Breakdown Structure have been identified in Chapter 8. This was supported by identifying and aligning a set of 30 BIM interactions that emerge throughout the WBS.

Finally, two ‘tools’ for deploying FP for lifecycle decisions in healthcare construction delivery were found to be flexibility and standardisation. This was initially explored in the Survey study (Chapter 7), and both constructs positioned in the concept of FP in the wider context of design theory. As presented in greater detail in Appendix B, standardisation and flexibility support design knowledge to the designer in narrowing the design space of solutions.

Research question 2: What is the role of BIM in answering how can the supply chain (consultants and contractors) deliver future-proof projects and how can healthcare organisations manage future-proof healthcare assets?

The second question was approached holistically too and elements of BIM have been distilled both from a supply and procurer side. In terms of delivery, the study showed that in particular six BIM capabilities can further support FP for efficient and effective enterprise asset management that supports lifecycle decisions (Chapter 7), In addition, the findings showed that BIM is highly interconnected to FP delivery activities as shown from the FP-BIM matrix in Chapter 8 where 30 interactions have been highlighted and further supported by evidence from practice.

From a procurer side, in the context of benefits realisation BIM is the communication vehicle that help procurers realise in particular four benefits: organisational performance, asset performance, lifecycle operational information and data maintainability (Chapter 8 and Appendix E). Furthermore, the findings suggested that

BIM is embedded in the wider context of the enterprise and a such organisational competences related to BIM have emerged after analysis of the data that were collected from the IPA (Chapter 8) and the case study (Chapter 7) and presented in detail in Chapter 9.

11.3 *Have the objectives been met?*

The following paragraphs justify how each of the objectives has been met and further align the outputs and thus the outcomes of this research against the objectives and research gaps (Figure 11-1).

Objective 1: *To identify flexibility and standardisation and their relation to future-proofing*

responds to the identified research gap 1. The objective has been met and the outcomes have been presented in Chapter 6, Appendix B and Appendix C. In particular, Appendix C was exploratory in nature and tested whether there is integration between standardisation and flexibility. The findings where carried further and in the next stage both flexibility and standardisation positioned in the wider concept of design theory. The findings suggested that flexibility and standardisation both support design knowledge (Appendix B).

Objective 2: *To develop a governance process for future-proofing in an owner operator enterprise context*

responds to identified research gap 2. The objective has been met and the outcomes have been presented in Chapter 7 and in Appendix D. A governance approach that relates to UK procurers has been identified as it emerged from the case study. The governance procedure has been described in terms of three agendas, namely government, strategy and information agendas.

Objective 3: *To identify a series of FP objectives and tasks across project delivery*

responds to research gap 2. The objective has been met and the outcomes are presented in Chapter 8 and Appendix E. A set of objectives spread across four main project phases have been identified and were further broken down into actionable tasks that emerged from relative literature review and tasks identified by the interview respondents.

Objective 4: *To identify BIM capabilities and interactions in a future-proofing delivery context*

responds to research gap 4. The objective has been met and are presented in Chapter 8 and in Appendix E. The six capabilities were initially identified from the case study in Chapter 7 and where further used to categorise 30 interactions that emerged from the IPA analysis in Chapter 8. The classification ontology in Chapter 8 map the 30 interactions between the FP-BIM framework in a delivery context.

Objective 5: *To develop a future-proofing deployment plan for adoption of future-proofing and innovation in an owner operator enterprise context*

responds to all identified research gaps in Section 1.1. The objective has been met, the outcomes emerged from the triangulation analysis and the discussion of the findings is presented in Chapter 9. The elements of the deployment plan cover various areas. A set of organisational competences that are applied across the enterprise have emerged. Performance measures are proposed that can be used so that procurers can evaluate the performance of the projects being delivered from the supply chain. A series of benefits have been identified which can be used as overarching targets across the enterprise. Finally, a delivery strategy is aligned in this context to further align future-proofing and BIM at an enterprise level.

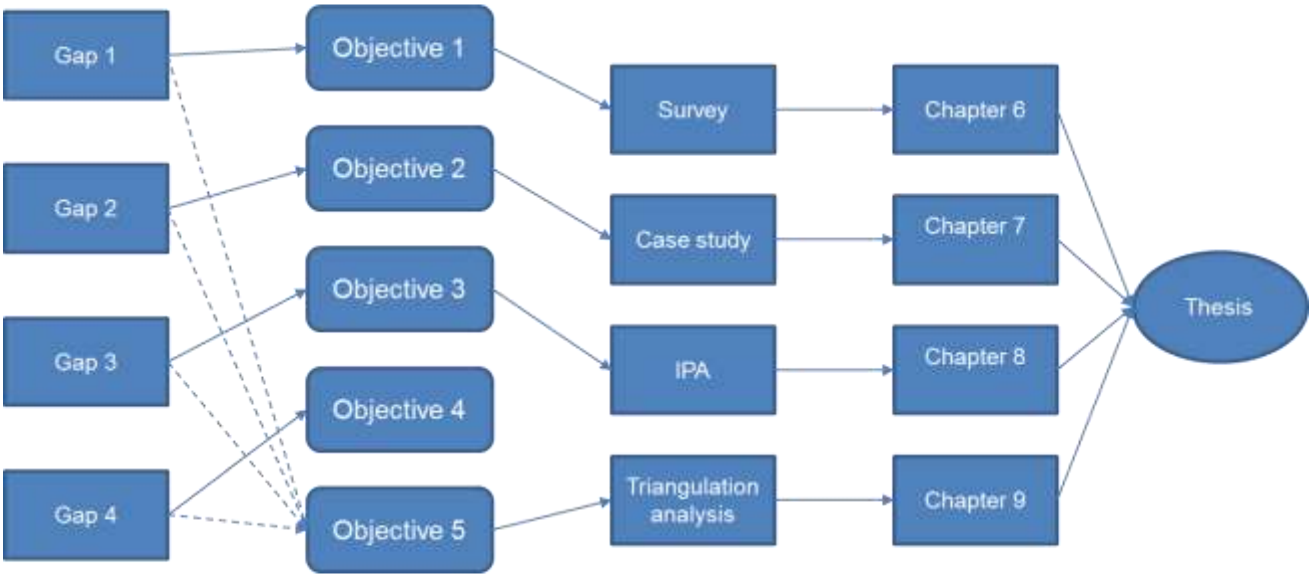


Figure 11-1: Objectives mapped against research gaps, outputs and outcomes

11.4 *Contributions to knowledge*

A synthesis of the multiphase design methodology outlined in (Figure 5-5, page 65) employed within this study resulted in seven key research outcomes:

- design knowledge can be increased with integration of flexibility and design standardisation (Chapter 6, Appendix B and Appendix C);
- FP strategies and BIM capabilities are the mechanisms for future-proofing lifecycle development at the early lifecycle stages (Chapter 7 and Appendix D);
- FP objectives and tasks for delivering future-proof projects (Chapter 8 and Appendix E);
- BIM and FP interactions for implementation of future-proofing solutions Chapter 8 and Appendix E);
- future-proofing competencies for healthcare organisations (Chapter 9);
- performance outcomes within a FP and BIM context (Chapter 9); and
- benefits realisation for healthcare organisations deciding to deploy FP and BIM in their projects (Chapter 8 and Appendix E).

The above contributions complement the aim of this study and provide essential tools for delivering and managing FP in healthcare industry. The study approached the concept of FP both from a procurer and a supply chain side and the outcomes reflect this holistic approach.

11.5 *Limitations*

As with all studies, there are limitations in this research too. Healthcare is a very complex and diverse entity, which covers criticality issues as well as political. Hence a single approach to delimitate uncertainty in its entirety is rather an ambitious goal. Despite this, recommendations are provided to consider future research. The following limitations are summarised below.

- This study used data from the UK construction industry. The mandate in 2011 signified BIM as an emergent and important concept and thus supply chain and procurers developed mechanisms that they could deliver and manage assets from their digital side. As such, the industry even not being fully ready had a better understanding and maturity than what industries in other countries might have. This, coupled with the fact that other countries' approach to BIM could be different suggests that the applicability of this study might need to be revised to take into account the changes of these variables.

- The research suffered from interviewing senior managers but with limited BIM experience. This was mainly because although in other sectors (i.e. education) the projects are very advanced in terms of implementation of BIM processes; in the healthcare sector there is potential for improvement. By the time data collection took place, BIM experts were considered to be 'doers' rather than decision makers, resulting in having extensive BIM knowledge but with limited views around the concept of FP.

- Future-proofing was approached from a change of use and/or function capability. Extreme environmental conditions, hazards, and other extreme phenomena were not considered. It also did not fully considered new methods of construction (such as 3D printing) or temporary construction solutions although it can be said that a more abstract and generic approach – design standardisation - was taken which finds application in many innovative construction applications. Having considered new methods of construction the concept of BIM and FP could have taken a different angle.

- BIM was approached from a management point of view. Although there were suggestions which address future software developments, no proof of concept was provided and as such the focus of this study was to provide a metacritique of BIM rather than recommendation for a proof of concept. Despite that, BIM was introduced in the wider enterprise context (i.e. organisational competences relevant to BIM/innovation).

- Despite the triangulation of the findings and validation of the results one significant limitation was identified. For the framework to be successful it relies on good BIM guidance documents such as asset data manuals, handover guidance documents, robust Information Requirements, BIM execution plans and other BIM management tools. It also relies on the organisation and the supply chain to have the necessary BIM knowledge and willingness to become BIM oriented.

- The study was only limited to interviewing healthcare construction experts and thus for linear projects the findings could be somewhat different. However, the objectives can be applied with minor modifications to sectors beyond healthcare (i.e. healthcare scenario factors may be replaced with relevant scenario factors found in the oil and gas industry etc.). Nevertheless it can be said that projects with great complexity, criticality and uncertainty can be highly benefited.

11.6 *Suggestions for further research*

Based on the research findings, a number of recommendations for future research are put forth. It should be mentioned that while this research focuses on defining a holistic concept with well-defined elements (the what), further studies can benefit from this research framework and use it to develop additional toolkits (the how). This will enable the true implementation of futureproofing in construction and effective adoption across the industry.

Considering that both two concepts are relatively new concepts in healthcare, more research and industry evidence is needed to foster the adoption of those two. The interaction matrix (Section 8.5) can be used as a framework for future research which stems from the identified synergies. The identified 30 interactions can be used as a framework for additional research to be carried out in more detail. The FP-BIM framework in Chapter 8 could be the basis for exploring new topics as they emerge from the identified synergies amongst FP and BIM. In addition, the identified six BIM capabilities (Chapter 7) could form the base for measuring cost efficiencies in projects due to the application of BIM.

Future-proofing could benefit by the use of Big Data. Research centres are stirring their efforts in this and proposals around new innovative ideas are introduced. Concepts such as Big Data and the Internet of Things can become reality in the near future. Those concepts combined with BIM would seem an exciting new opportunity for mitigating uncertainty. Data analytics could be employed and be used to predict future trends and mitigate risk.

Future-proofing came in light from the sustainability agenda but in literature it was often overlooked. As such, further research is also required to develop appropriate metrics for incorporation of FP into sustainability assessment tools such as BREEAM. As such a series of project KPIs would seem beneficial and allow stakeholders to improve better monitor whole-life performance and incorporate this into their governance procedures.

Future-proofing and Information requirements could benefit from integration of BIM and Requirements Engineering. The industry should break the silos and explore the true potential of creating and sharing data by expanding information requirements procedures beyond CAD. This will truly allow for holistic decision making and bring a starting with the end in mind mind-set to all stakeholders.

Future research should consider possible methods of integrating standardisation and flexibility within a BIM environment as showcased in Chapter 6. This will offer explorations in Human-Computer Interaction for new design practices. Another gap that was identified is the need for design guidelines that will focus on the application of conceptualising the design of flexible healthcare facilities with BIM. The guidelines should consider: identifying spaces that frequently change; design standards that should be employed in order to apply flexibility; applications that could allow explorations of *“what if”* scenarios with BIM; and the evaluation methods within BIM that would test those scenarios.

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APPENDIX A

Design of Flexible and Adaptable Healthcare Buildings of the Future – a BIM Approach[13]

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The UK's Government Construction adviser announced that all the public construction will be implemented with BIM in the coming years. This decision affects dramatically the design phase of healthcare facilities as by 2016, BIM is mandatory in the implementation of the design process. Moreover, The UK Construction Strategy plan does not offer for investigating the multidisciplinary design space of possible solutions. The uncertainty that impacts on healthcare (demographic trends, changing patterns of disease, technological advances and clinical knowledge) has led healthcare policy makers to take action to manage demand for healthcare services and the supply enabled by healthcare infrastructure. A state of the art review of literature identified that healthcare facilities are not designed to be change-ready and that owners of such facilities have dynamic requirements. To future-proof healthcare facilities a design process is required to offer a collaborative, parametric lean construction practice that enables the design team to generate and analyse flexible healthcare building design spaces based on multi-stakeholder requirements. BIM and Integrated Project Delivery (IPD) offer dynamic decisions early in the design process. Here, IPD, the RIBA Outline Plan of Work 2012 and the BIM Guide from the Computer Integrated Construction Research Program were used to define the exact information exchange between the parties in a BIM-based construction process for change-ready healthcare facilities. A generic process map is derived from the literature for future testing and is presented in respect to the principles and philosophies of process protocol.

Keywords: conceptual process map, design space, flexibility, healthcare facilities, parametric modelling.

[13] *Krystallis, I., Demian, P and Price, ADF, 2012. Design of Flexible and Adaptable Healthcare Buildings of the Future – a BIM Approach. First UK Academic Conference on BIM: Conference Proceedings, Newcastle, 2012, pp. 222 - 232*

INTRODUCTION

The NHS along with the Private Finance Initiative (PFI) was procuring over 70 new hospitals by 2002 (Worthington, 2002). RIBA (2007) outlined the Work Plan of such contracts but the suggested process did not provide a building that was adaptable nor the process of design was BIM oriented. Similarly the RIBA (2012) Outline Plan of Work is indeed updated to BIM working methods but yet again the design process does not provide a facility that can respond to change. Moreover, PFI contracts do not support flexibility; the "2020 vision" highlighted that many of the healthcare buildings could be obsolete the day the start (Worthington, 2002). Kendall (2005) argued that many large facilities become "complete" over time, incrementally, but are never really finished. Moreover, Kendall argued that it is not appropriate to design for one fixed solution; since the organization's requirements (and consequently the building's requirements) are constantly changing through time; so the design must allow the building to adapt to future circumstances. Current approaches, referred to the Pre-BIM stage, have been characterised by their inability to deliver *collaboration* among the stakeholders as well as asynchronous workflow. Automation and sharing of information such as quantities, cost estimates and specifications is neither derived from the design documentation nor linked from other documentation. Taking advantage of technology in order to deliver better outcomes is at a minimum level (Succar, 2009).

Doubts have been expressed, as to whether new healthcare buildings being built today are able to adapt to society's changing needs in the future (Worthington, 2002). The NHS Confederation briefing (2010) explained that new buildings should be capable to provide efficient, safe, quality environments to meet the needs of a modernised health service. Accordingly, buildings are linked to healthcare systems and while systems are evolving through time, so buildings have to follow in order to have consistency in the healthcare sector. Finally, the understanding that there is no best solution (de Neufville & Scholtes, 2011) will force the project team to deliver a design modifiable to new circumstances rather than one which responds to fixed requirements.

Integrated Project Delivery (IPD) requires all participants to start as early as possible in the implementation of a BIM project (AIA, 2007). Proposals for BIM implementation are continually developed and additional participants are added to the project to make the required modifications, and updates to eventually maximize the project's deliverables (CICRG, 2010). BIM has been characterized by the UK Government’s chief construction adviser Paul Morrell as *"unstoppable"* regarding its rise in construction (Fitzpatrick, 2012). Additionally, Morrell sees such potential in involving BIM in design, construction and operation of buildings that by 2016 all public construction projects over £5 million will be implemented with BIM. Kymmell (2008) stated that BIM is not a single static model of a project. The components and the information that shape a BIM model are continuously evolving as the project steps from one phase to the other. Significant changes might occur to both the 3D designed components and their linked non-3D information. The recognition of this continuous change makes BIM a dynamic process.

The design process entails proposals, testing and modifications. During conceptual design, it is necessary to justify the design concept step by step. This justification will provide the design team the required knowledge to understand the relationship between the suggested scenarios and the design's responses to these scenarios. The objective of this validation is to strengthen the proposed solutions, used methodology, methods, tools, etc. It is important to know when and what kind of decisions should be made, and how to make them. It is not unusual to see conflicting objectives which render decision making challenging.

Recognition of changing design criteria and requirements brings parametric modeling to the forefront. This new design approach has the ability to adapt and respond to the aforementioned issues, making parametric modeling an effective approach for the designer who investigates solutions for complex and dynamic designs. Research so far has explored systematically many of the possibilities using scenario planning and parametric processes of the requirements and the designs (Gane 2011; Koppinen & Kiviniemi 2007), but this does not necessarily mean the resulting design itself will be flexible. It only means that the resulting design is the best design at the time for that set of known requirements and scenarios. What if the requirements or scenarios change in an unforeseen way? Or what if one of the requirements is that the building must be change-ready? The following paragraphs explore this need for flexible designs.

Aims and Objectives

The aim of this paper is to propose a conceptual process map to apply BIM for implementing flexibility in healthcare facilities.

The objectives of the paper are to:

- develop a state-of-the-art through a review of literature on design theory, flexibility and BIM implementation;
- identify benefits of adopting flexibility early in decision making;
- categorise types of flexibilities regarding function, capacity, flow and time; and
- identify key requirements, stakeholders and design methods to affect the conceptual design process.

METHODOLOGY

Information for the literature involved collecting of both online and offline publications. Literature search was categorised into three basic categories: healthcare; flexibility; and BIM. Literature review was used to recognise healthcare drivers and to identify flexibility as potential solution. BIM technology is suggested as a prism to reinforce design for flexibility and a conceptual process map was developed to describe a conceptual design process (see fig. 1).

LITERATURE REVIEW

Design Logic

Simon (1969) described design as a problem itself that requires answers. A design problem cannot be solved from a single best solution, but from a set of satisfactory solutions. Hence, the designer is expected to define or redefine or change the design problem as it is determining through time while exploring the *design space* of possible solutions (Cross, 2001). The process can be divided into two environments: the *inner environment* of the design problem represents the alternatives, a set of variables that require an understanding of the design and operation of the system. The *outer environment* is a set of parameters derived from system's requirements and a set of probability distribution; the key performance drivers. Krishnamurti (2006) described how the design team seeks to provide solutions to problems through the following equation:
design space = problem space + solution space + design process;

and further explained that the design process and the design problem are banded together. Akin (2001), as described by Krishnamurti (2006), analysed the design process as the sum of the design knowledge and strategy, whereas strategy refers to the search the design team carries out and design knowledge stands for all the means the design team uses to represent the multiplicity it needs and finds useful. Such representations could be the design's team actions, design states etc.
Two strategies occur to explain the process of constructing a *design space* according to Fricke (1996); *Stepwise process-oriented*, where the design team is considering all the relevant problem areas and holds a more abstract level of solutions before becomes more concrete; and *Function-oriented,* where the designer focuses on one problem area, solving it from abstract to concrete level and then continues to seek answers to the following problems.

Design process towards BIM

The key principles behind the design process according to Kagioglou et al. (2000) and later defined by Koppinen and Kiviniemi (2007) are:
Whole project view: The whole process of the project is documented from recognition of a need to the whole life-cycle of the project, that is operation and maintenance;
Progressive design fixity: The planning of BIM implementation is formed throughout updating the design information. When the design solution becomes concurrent the information can be more detailed and the detailed process of the design begins;
A consistent process: The ability of a BIM process to provide with its generic properties a consistent application. A concurrent design process will reduce uncertainty experienced by the stakeholders;
Stakeholder involvement/Teamwork: As the name suggests, Building Information Modeling is a process that focus on information and particularly it requests from the stakeholders to have the right information at the right time. Consequently, decision-making is encouraged and enforced in the process;
Co-ordinator: Effective coordination between the stakeholders as well as the coordination of their design models is fundamental; and

Feedback: Positive and negative feedback can be useful to improve processes and identify improvements.

Types of Flexibility to support design knowledge

Flexibility is the proposed solution to contemporary problems related with technological, social and economic changes (Kronenburg, 2007). Flexibility can be discussed from the perspective of how the building is changing. The designer can find in types of flexibility the *design knowledge* he seeks in identifying the design process he needs and finds useful. Slaughter (2001) discussed types of changes that may occur regarding its *function*. For a healthcare facility, such changes may occur in *re-using existing functions* – upgrading an existing space for better performance; *creating new functions* – creating an existing space for additional functions; or *changing for different functions* – altering the space for different functions to apply. This *spatial transformation* will allow the space to adapt to different circumstances. Kronenburg (2007) categorised this kind of transformation under adaptable strategies.

The second type of flexibility is related to the *structural transformation* of the building to meet specific performance requirements. In this situation, problems may occur regarding its *capacity*. Changes in capacity may occur from changes regarding the building's *volume* and/or *loads*. These sorts of changes focus on *size*. Structural transformation is more rigid than in strategies that occurring in spatial transformation and because in some situations the structure is affected, these types are also more expensive. Kronenburg (2007) categorised this kind of transformation under transformable strategies. Lastly, the third type of flexibility is related to changes regarding the building's *flow*. Changes in *environmental* flows may require a change to occur due to a climatic change and change in flow of *people/things* may occur from an organisational change.

Additionally flexibility can be considered from a *time* perspective. De Neufville et al. (2008) categorized flexibility into three types that could be applied in healthcare: *Operational*, *Tactical* and *Strategic* flexibility. Each type of flexibility can be considered as moving from one level to the next and forcing the building to adapt to changing needs more dynamically.

- *Operational* or *short-term* flexibility is the lightest form of flexibility and the easiest as it can be applied on a daily or weekly basis. Systems that can adapt to that strategy are light systems such as furniture systems and are less cost effective and money-saving while endorsing a rapid on-going change;
- *Tactical* or *mid-term* flexibility deals with space. Light components can be used to change the space of the area and therefore giving the preferred result. In order for this potential to work, the initial cost of the structure should be higher than the standard cost and it is also applied in more than a week; and
- *Strategic* or *long-term* flexibility is a strategy that hospitals can apply considering the end use of the facility. The effort of hiring this option is to significantly increase the life expectancy of the structure.

DISCUSSION OF THE CONCEPTUAL PROCESS MAP

From an IPD perspective, the *design space* is usually formalised not by a designer, but by the planning team. The planning team adopts a *stepwise process-oriented* approach because of the many requirements that have to justify - the *outer environment*; and due to BIM technology, the members provide multiple design disciplines - the *inner environment*. Apart from reduction of design errors, the planning team also offers an insight into design problems and presents opportunities for a design to be continuously upgraded. This multi-aspect design collaboration and exchange of knowledge applies value engineering much earlier than in Pre-BIM phase and finally provides a future-proof design. The structure of the proposed conceptual process map is in respect to the principles and philosophy of the Process Protocol as was undertaken by the University of Salford.

Building requirements and stakeholders

Identification of the planning team is particularly important in an IPD project. The owner, designers, contractors, engineers, major specialty contractors, facility manager, and project owner have to be identified as early as possible (CICRG, 2010). The team can be subdivided into two categories: the *primary* participants; and the *key supporting* participants. The allocation of a member to a category depends on their importance and evolvement throughout the project's lifecycle (AIA, 2007). In this phase, the planning team's main aim is to satisfy the client's business goals and requirements. Additionally in this phase the determination of *what* is going to be built, *who* will built it and *how* is established is satisfied (AIA, 2007). The client organisation's requirements as well as the engineering requirements are the first step that needs to be documented and managed. For a healthcare project a set of probabilistic distribution may derive from the need to establish projections of annual demand, whereas the Activity Database (ADB, at set of standard designs endorsed by the Department of Health) provides technical specifications (engineering requirements) which the design should follow. In more detail, such requirements can cover the building type (derived from ADB), the various aspects of the organisation's aims, operational activities, spatial needs, condition requirements and costing target. Cost estimation as early as possible helps to determine the price of different factors and enables realistic designs later in the process. Accordingly, other stakeholders' requirements (electrical, civil, and mechanical) need to be documented and discussed in order the *deliverables* to be discussed.

The design team's interest is to deliver a change-ready facility, therefore the *deliverables* that occur from briefing and spatial program are a categorisation of spaces depending on the need to be flexible as, *flexible spaces* (FS), *inflexible spaces* (IS) and *partially flexible spaces* (PF). For example, highly serviced environments such as clinics have more needs than consulting rooms have. Due to their needs to serve patients more effectively, they are likely to change more frequently. In this respect, the area that will be used for consultation can be less expensive and also less flexible whereas the clinic area that needs to be change-ready and therefore highly flexible could probably cost more to be built. Additionally, the planting system has to be in a respectful distance from a clinic that has been scheduled for possible expansion in order to allow the building to accommodate changes whenever it is required.

Design Brief Implementation

In the second phase of the conceptual process map the *inner environment* is taking place in order the inception of the conceptual adaptable product to be formed. It is critical that the team members evaluate the importance of the information they developed in the *outer environment*, as the information will be used again in subsequent phases (CICRG, 2010). Brand (1995) argued that scenario planning (SP) has become so turbulent that traditional forecasting seems useless. SP can provide different directions and options of different assumptions. It helps the design team explore the future Built Environment from different angles. This exploration can be utilised through the investigation of the application of the various types of flexibility (see 1.3). SP is suggested to be the mean that will bring important assumptions as to what is required to be considered for the design decision of the building; in other words, implementing a planning approach of possibilities of different parts of the building that could be able to change at different levels providing value for money and also to be more valuable as a construction (Francis, 2010). A brief categorisation of different levels of spaces that derives from requirements is described in 3.1.

Activities such as *Target Value Design (TVD)* can be used as a mean for cost estimating. The design team optimises the client's requirements as well as the engineering requirements as they were set in the previous phase. TVD is following the principles of Lean Construction methods and is applicable especially in large healthcare projects (Tiwari et al., 2009). Adoption of TVD means that cost is a target (target costing) that should never be exceeded. This can be achieved through tracking the cost estimate and budget by using model cost estimating to inform TVD at this stage. Whereas in Pre-BIM, delivery approaches, cost comes after design; in a TVD approach cost sets the limit as to what should be designed in order not to overcome it. Flexibility is measured and implemented in response to cost. From the discussion in 1.3 it derives that a change in windows (environmental flow) will cost less when compared to a vertical expansion (change in loads).

The constructors as *key supporting* participants of the project are used as advisers (AIA, 2007) on topics in which they are specialists. The main project team can identify how to provide flexibility in the project based on three construction applications (Slaughter, 2001). As further investigation to their applicability these approaches are not strict, in a manner that they should be implied individually and fixed. They can perfectly be combined to accomplish the desired solution that is entitled to find answers to a forthcoming situation.

- The first approach *separating systems* is based on architect Frank Duffy and then elaborated by Brand (1995). In short, different parts-layers of the building structure have different lifespans. Design for flexibility allows that layers to be replaced or changed whenever needed;

- the second approach is referred to as *prefabrication*. Modular design supports standardised units or standardised dimensions to support construction (Waskett, 2003). Prefabrication is described as an advanced construction technology and allows the building to be flexible in a short time while keeping low costs (de Neufville et al. 2008); and
- the third approach is to design for *overcapacity* so that to forestall future changes and needs. Adoption of this approach helps in cases were no replacement or extension of current capacity capabilities is welcomed. The contractors and subcontractors can advise the project with information regarding for example off-site components, materials' attributes and how the project can be benefited in terms of cost and flexibility.

Concept evaluation and approval

Parametric Modeling (PM) drives BIM to provide the project with objects that are attributed with information rather than vague lines (Autodesk white paper, 2007). Robinson (2007) argued that a BIM platform is ideal for visual project management to explore alternative scenarios due to its parametrical ability to present objects. PM has been described as a process of making geometric representations of a design with components and materials attributes that have been parameterized. Geometric entities and their relationships are represented within a BIM environment. PM offers the potential to perform transformations that occur from different configurations of the same geometric components (Turrin et al., 2011). Aish and Woodburry (2005) argued that parameterization offers the designer the ability to build a model "as a typically infinite set of instances, each determined by a particular selection of values for the model's independent variables".

The latest BIM technology has offered the ability to define parametric constraints within the objects parameters so that when changes occur in the model, certain geometric relationships remain as their constraints impose them. Moreover, PM enables objects to self-configure their assemblies regarding a change that is made to alter the model. Each alternative solution that is generated in phase 3.2 through the various scenarios here is evaluated under the predefined set of requirements (see 3.1) and to narrow the number of alternatives a single model should accomodate, the model should be parametrically defined with constraints and attributes (Anderl & Mendgen, 1996). In this respect the project team will spend more quality time to measure the performance of each scenario and narrow the *design space* of solutions. The end of this third phase of conceptualisation will bring the completion of a conceptual adaptable product. After validation and conceptualisation of the *design space* of solutions the project team proceeds to the next phase of the project, that is the criteria design phase (RIBA, 2012).

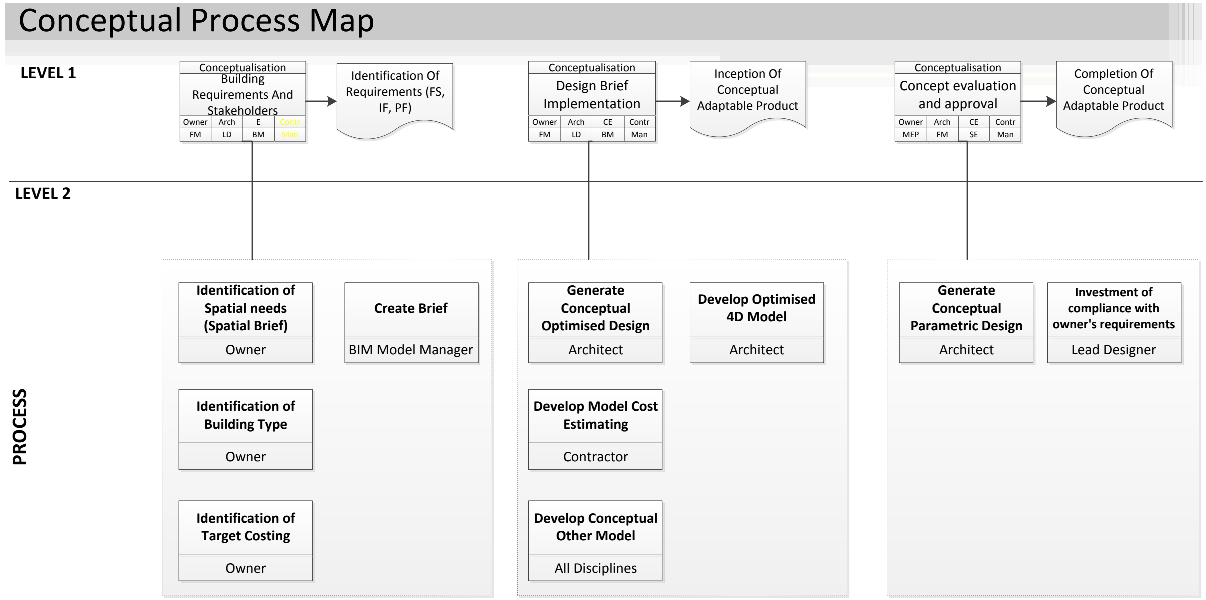

Fig. 1: Conceptual Process Map.

CONCLUSIONS

Design space can be complex and unfamiliar by considering an increased number of aspects. Moreover accepting a "best" solution may be a difficult process and also finding an "optimal" solution may be even more difficult, considering that the evaluation criteria are not clearly outlined (Watson, 2011). Design exploration with parametric modelling provides a flexible and responsive representation that the final product (and consequently the design) can respond to change. Moreover, the process is following the principles of IPD, as value engineering is achieved throughout the process by the participation of all team members during the early design-decision stage. However, the provided flexibility arises from the parameters the designer sets, in other words flexibility is limited and depended by the parameters. Additionally the load of information and the time needed to parameterise requirements to constraints and attributes of alternative solutions can be time consuming and requires effort and knowledge by the practitioner. Moreover, if there should be a change in the design fees and if yes then how they should be applied must be clarified. Lastly, questions arise as to how the procurement and ownership of a healthcare project that is designed to accommodate changes might be affected since most of the projects are under PFI contracts. This needs to be cleared out from both a capex (capital cost) and Opex (operating cost) perspective.

FUTURE RESEARCH

This paper is part of an on-going research. Part of the future research will investigate to which extend BIM can offer different modes of interaction with the design-decision team (incremental improvements within the organisation), and/or potentially new forms of processes during the early design stage of change-ready healthcare projects (re-engineering the whole process). Furthermore, the suggested conceptual model map should be validated. Future methodology will be conducted in order to improve and validate the process map and surveys as long as case studies will be used for the validation.

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APPENDIX B

Supporting Future-proof Healthcare Design by Narrowing the Design Space of Solutions using Building Information Modelling[14]

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BIM has been characterized by the UK Government's chief construction adviser as unstoppable regarding its rise in construction and he further positioned BIM as mandatory for public projects in the UK by 2016. Moreover, large scale public projects such as healthcare facilities must be seen as a process, being able to meet the constantly changing demands imposed on healthcare infrastructure. The designer should design a facility that is change-ready rather than a facility designed to meet fixed requirements. Therefore the designer should accommodate as large as possible a section of the design space of possible solutions instead of mistakenly narrowing the response of the project to only one solution. Scenario based design and rapid prototyping where employed as research and design methods for the proposed software modules the Activity Database (ADB) add on could accommodate. Three modules derived proposing a method that will offer insight regarding spatial information through partially automated knowledge extraction. Additionally, it is proposed on how to link the concepts of flexibility and design standardisation. The proposed design approach will provide richer knowledge representation at the early stages of the project in less time and effort.

Keywords: Decision theory, Healthcare, Information extraction, Information technology, Standardisation.

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INTRODUCTION

The UK Government and industry provides standards and guidance for the design and construction process of healthcare facilities in order for the design process to address the needs of all the stakeholders (patients, medical staff, owners etc.) by defining procurement methods (NHS 2011), construction strategies (Cabinet Office 2011), overlay plans of work (RIBA 2012), and technologies to be used (CIMCIG Admin 2012). These result in more standardised processes and products. Additionally, programmatic requirements and best practice for the design of healthcare facilities are provided through Health Building Notes (HBN), Health Technical Memoranda (HTM), Activity Database (ADB) and in the DH Schedule of Accommodation. Additionally, the Department of Health commissioned the Procure21+ framework "to improve the procurement process for publicly funded schemes and create an environment where more value could be realised from collaboration between NHS Client and Construction Supply Chains" (NHS 2011).

In cognitive science, parallels have been frequently drawn between design and playing chess. Conceptual design has long being recognised as an ill-defined process (Reitman 1964, Simon 1974). An early design problem does not have a clear statement, the constraints are not clearly defined but fairly general objectives are set which leaves the designer with large choice of solutions representing a chess-like design approach which "is rather like playing with a board that has no divisions into cells, has pieces that can be invented and redefined as the game proceeds and rules that can change their effects as moves are made" (Lawson 2004: 20).

Global austerity measures are causing reduction of investments in all sectors, and the construction sector is no exception, however, owners are seeking other ways to overcome the financial crisis by investing in the application of the sustainability agenda; and for a building to be sustainable designers recognise that it has to also be flexible and adaptable (Krygiel and Nies, 2008). Yet, introducing sufficient flexibility to future-proof the design of healthcare facilities is still a rather abstract process. While a specialized (mostly architectural) body of research has identified various types of flexibility that a facility can satisfy, there is little research regarding how this can be captured in the design process through design standardisation.

Design standardisation can help to make flexibility quantifiable. With BIM technology there is potential to increase the procedural designer's knowledge to manage, apply, edit and test "chunks" of design information; rather than manipulate meaningless lines as one used to do in using previous CAD systems. The proposed design methodology is focused on two design aspects: to allow the user to test, during the conceptual stage, "what if scenarios" for future refurbishment in order to better future-proof the project; and to allow an automated comparative analysis to take place in existing refurbishment projects between an existing space and proposed alternatives in terms of cost, timescale duration and best matching attributes. Adoption of the proposed design methodology will allow parts of conceptual design to be standardised and automated in terms of narrowing the design space of solutions while better exploiting the power of IT. Eventually, this will allow testing more "what if scenarios" in significantly less time and with less effort. In this paper the theory underpinning the proposed design methodology is described whereas in the next phase this concept will be tested in various case studies. *Literature Review*

Theories in Layout Planning

Different cognitive processes may be used to generate spatial layouts. Eastman (2001) described two extremes for design generation. The first extreme is external representation, where the design is composed and refined by the designer by controlling the symbols and structure of it. The other extreme is internal representation, where the designer builds up the design in his/her head until it satisfies the set criteria and then proceeds to the external representation. Recent advances in research seek to understand how the design process unfolds, and the role of computer systems in that process. This often leads to the design of human-computer interaction. Two paradigms describe two different worldviews: the computer-supporting-human paradigm and the computer-controlling-human paradigm. The latter, often referred to as emulating design (Cross 1999) can be compared to the computational process that chess-playing machines adopt. Efforts to adopt such a process failed in the history of design cognition. The example below can best describe such efforts.

In the mid-90s, a project "Can a machine make aesthetic judgments?" (Glaze et al. 1996) aimed to establish rules of aesthetically "bad" design since the research team concluded it was not possible to establish rules of aesthetically "good" design. The researchers collected amateur designs and submitted them to expert graphic designers to critique them. The team subsequently converted the comments on the "bad" design features into "rules", and later the team tested these rules by using themselves as "human-computers" (i.e. the team followed the instructions in a machine-like way).

Finally, the team applied the rules to a new sample of drawings and compared the "machine" results with those of the human experts' critiques of the new drawings. The interesting point was that only a small number of rules could be applied to the new sample in order to eliminate common "bad" design features. What was even more interesting was that even the experts were found to be inconsistent in applying their own rules. The explanation given by the expert designers was that though the "rules" were correct, their applicability was not a standard in every case.

This experiment presents the notion that there are some things such as "aesthetic judgments" (or for the purpose of this study "flexibility judgements") in design where the "human attribute" cannot be emulated by the computer to a satisfactory degree. Consequently, there is a need to understand why people design first rather than try to automate how they design (Cross 2001). The first paradigm, often referred to as supporting design, accepts the computer to be the agent where, instead of controlling the design process it supports the thinking of designers by providing different capabilities, such as being web-based, learning and/or being pro-active (Lawson 2005) and that envision brings BIM into discussion.

Parametric Object-based Modelling

IT and specifically design computing has increased users' expectations. Parametric Object Modelling (POM) is linked to creativity in architectural practice and as the results of the survey by Ahmad et al. (2012) suggest, POM has the potential to enhance the whole process of design decision making and problem solving. POM engines use parameters to determine the behaviour of a graphical entity (the object) and define relationships between other modelling objects.

Object CAD technology may provide the same graphical and geometrical representation output as a parametric building modeller; but that does not mean that the information of the CAD model will be as rich as in the BIM model. "Current file based CAD and object CAD tools may be used to some degree to support BIM, but require myriad supporting technologies and the aggregation of information across diverse, independent applications" (Autodesk white paper 2007:5). As a consequence, CAD and Object CAD technology cannot offer real time coordination (simultaneously updating a change in all views of the model) when a change in the design occurs and as a result integrity and confidence in decision making are put to question (Autodesk white paper 2007). POM offers a whole new approach to design, beyond CAD and Object CAD. For example, instead of capturing a wall by a set of lines using standard tasks such as offset, mirror etc., the designer can create an object by choosing it from a predefined library of object classes and instantiating that object. This parametric design paradigm has led to the creation of a library whereby whole healthcare rooms can be inserted into a design model, with their objects attributes, engineering requirements and clinical functions through the Activity Database's (ADB) add-on for BIM platforms.

The ADB add-on for BIM platforms

The ADB toolkit (first introduced in 1970s by the Department of Health (DH), the Social Services and in collaboration with the Regional Hospital Boards) contains information intended for use by healthcare estates and facilities professionals. The database comprises information regarding departments, rooms, assemblies and components and can be used in both the initial stages of the project, as well as in later stages (detailed design). Through ADB, the DH provides design standards that satisfy the department's requirements. The ADB add-on for BIM software allows the designer working in a CAD or BIM environment to insert a room with all its components directly in the layout. There is a list of all departments and all room types. It allows the designer to check the BIM model against the ADB Project Database. This automatically checks the room's equipment and if there are any mismatches the software will highlight them on the layout. Additionally, the designer can create schedules out of the layout in terms of room schedule or in terms of room

equipment. Additionally, the existing ADB information architecture represents all rooms using a clear and precise set of attributes (ADB add-on white paper 2012).
During design, the designer can manipulate data of more than 1200 room variations – a vast amount of information to be managed, the add-on does not offer a method that will limit the design space of solutions within the BIM system. The designer is expected to exploit processes outside the BIM environment, such as retrieve information from previous projects, or to rely on his/her previous design experience or other design precedents (Lawson 2004) to identify possible solutions. This research offers insight to narrow the design space of information management where the system offers partially design knowledge according to the designer's preferences.

METHODOLOGY

Two modules are proposed to extend the ADB add-on that will enhance the information extraction experience within BIM. Scenario based design (SBD) was employed as method to develop the proposed modules. The modules extend the ADB add-on by: organising attributes of rooms and components into categories and subcategories, and sorting solution spaces based on the cost of applied changes or by the time they need to be fulfilled or by the number of attributes/filters that are satisfied. The two modules are described on the following sections. Due to limited space, only one refurbishment problem scenario is presented here. Problem scenarios referring to "what if scenarios" for testing future refurbishments during conceptual design are not discussed in this paper. Problem scenarios are the means to describe a user's engagement and her interaction with the system and "a key result of requirement analysis" (Rosson and Carroll 2002: 12).
Problem Scenario: The healthcare estates manager and the owner of "Town A Hospital" want to change a clinic's utilities room because it is of no use to the staff. They first open the BIM model to check whether the design team that built the facility some years ago included in the study any alternative scenario for the space in question but they do not find such information. They want to substitute the existing space with another space but they do not know what the best options for that particular space are, so they communicate with company X that has established its name in the field of healthcare design. Alex, who works for company X, receives an email with the BIM model of the healthcare facility for which an alternative layout was requested. She opens the BIM model and wonders about the choices she has to change the space in question to another space. She refers to the ADB room database but she gets stuck as there are more than 1200 room variabilities that she needs to check against the existing space. She then goes to Bob, the senior designer and asks him based on his experience working on previous healthcare projects if he ever faced a similar task of alteration of a space with analogous requirements. Bob tells her to open the file of "project B" they worked on 3 years ago.

Alex goes through the files of the project and she finds the original layout and the revised refurbished layout. She sees in the first layout a room similar to the utilities room in her current project that was later changed to another room type, but she cannot find what made this choice the best available solution so she goes back to Bob. Bob tells that was the option the owner preferred from a list of space solutions provided to him. Bob then forwards her an Excel spread sheet where the problematic room was checked against other rooms based on a list of engineering requirements (such as cost of refurbishment, clinical functions, environmental conditions, area constraints, duration of change etc.). Alex opens the file and marks down the nominated rooms and their cost refurbishment and forwards the file to the healthcare estates manager to decide what room is more suitable for the hospital's needs and budget.

THEORETICAL FRAMEWORK FOR FUTURE-PROOFING THE CONCEPTUAL DESIGN PROCESS

The discussion of this section presents the theoretical framework upon this study was based (Figure 1). The goal of narrowing the design space of solutions emerged from the concepts of decision making in design. Simon (1996) described design as a problem itself that requires answers. According to Newell (1979:5) "a problem space consists of a set of symbolic structures (the states of the space) and a set of operators over the space". Additionally, there is no linear process from problem to solution (Lawson 2004) and since there is more than one problem spaces (Newell 1979) design seems to be the only means to drive to "satisficing" solutions (Simon, 1996). Krishnamurti (2006) described a design space as the sum of the problem space, solution space and design problem.

The problem space is shaped only by the potential solutions that satisfy the established requirements. The solution space on the other hand is formed by all potential solutions for a given design problem. The design process consists of procedures used to develop candidate solutions from requirements. Akin (2001) analysed the design process as the sum of the design knowledge and design strategy, where strategy refers to the search the designer carries out and knowledge stands for all the means the designer uses to represent the multiplicity she needs and finds useful. Such representations could be the designer's actions, processes, design states etc.

Moreover, Fricke (1996) categorised strategy into Function oriented, where the designer focuses on one problem area, solving it from abstract to concrete level and then continues to seek answers to the following problems, and Step-wise process oriented, where the designer considers all the relevant problem areas and holds a more abstract level of solutions before becomes more concrete. Regarding knowledge, from on-going research (Ahmad et al. 2013) it is recognised that "satisficing" healthcare design solutions will emerge from the application of flexibility, design standardisation and the information management abilities of BIM.

Application of Future-proofing Conceptual Design Process

Having discussed, in the previous section, the concepts driving the proposed process, the application have been discussed in this section (Figure 2). As previously mentioned, there is more than one design problem; consequently, for the design of healthcare facilities, such problems regarding information could be caused by many factors, for example: the information the design team receives from the brief with the client and the information the design team receives from computer systems, such as the vast information that is contained within the ADB add-on (Stage 1).

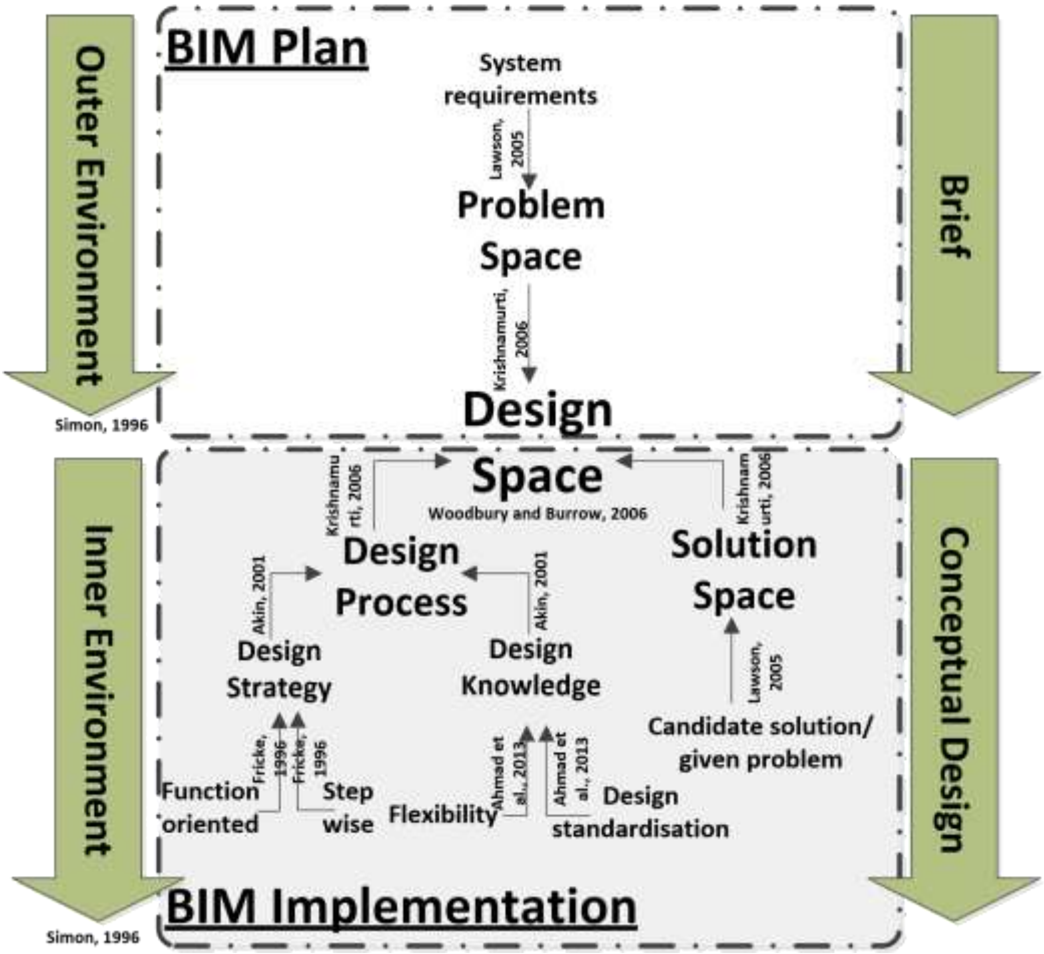

Figure 1: Theoretical framework-future-proof Healthcare design by narrowing the design space of solutions.

Future-proofing healthcare design towards "satisficing" solutions within BIM is achieved by adopting a function-oriented strategy, e.g. solving one problem (room or space) at a time (Stage 2). Automated design knowledge, the other component of the design process, is exercised by investigating two space attributes: flexibility and design standardisation (Stage 3). Design standardisation is applied in terms of managing the vast information that exists within the BIM system and BIM attributes are classified based on numerical and textual values. The BIM system identifies common information that is contained within the ADB rooms, such as attributes with the same textual values (e.g. Type A carpet) and numerical values such as width of a room. This process allows the grouping of ADB attributes into category filters and sub filters (Module 1). From literature, it is concluded that flexibility is clarified as the total force of two other forces-effects. The identified relationship between these two effects can be analysed with change effect being the independent variable and timescale duration effect being the dependent variable. Slaughter (2001) categorised flexibility in regard to change and three categories emerged, namely change in people/flow, spatial change and structural change. Alternately, De Neufville et al. (2008) categorised flexibility in regard to time, hence the three categories that emerge are short-term, mid-term and long-term. The three stages of change effect provide knowledge regarding the duration of a substitution of two spaces. For example, a change from Type A Office to Type B Office can be short term if involves only a change of people. On the other hand, if it evolves demolition of walls to extend the area then it is a spatial change (Module 2).

Another way to measure the proposed alternative solutions is to assign refurbishment costs to substitutions between the existing space that is nominated to be substituted and the proposed alternative solution spaces that emerge from Module 1. For example, the utilities room that was to be substituted would be checked against the list of rooms that emerge from Module 1 (Stage 3a) and then the user will prompt the computer to sort out the alternative list of solutions from least expensive to most expensive substitution. Therefore, the independent variable this time is change effect and the dependent variable is cost effect (Module 2).

The mechanisms that emerged from the function oriented strategy and the automated design knowledge drives finally towards a space of solutions, that is a list of proposed ADB rooms that results to a narrowed design space of satisfactory solutions (Stage 4) and finally the design team along with the owner of the project can conclude in choosing the most effective alternative spaces that emerge through the aforementioned process.

Modules for Supporting Design Space

The existing ADB information architecture represents all rooms using a clear and precise set of attributes. In a BIM model, ADB information is captured within the rooms or the components of the rooms. The two modules described below were developed to address the issues that emerged in the problem scenario where Alex the designer was struggling to find a quick and reliable solution as she could not handle all this vast information that was contained within ADB. The first module is the option to categorise attributes based on what they represent. For example, the spatial category will include the subcategories, length, width, height, area and volume. The user will be able to choose one or more subcategories of that category, so that when the query search presents a list of results, only spaces that satisfy all the preselected options will appear. Through that action the user can filter the vast amount of proposed rooms that is available in the ADB database. For instance, Alex might want to keep the same flooring material (material attribute) and the medical equipment (components attribute) to the room the estates manager wants to substitute, so she clicks only on those filters that satisfy the briefing requirements. She then runs the query and only rooms with the same selected attributes will appear as possible solutions. That means that the designer has to be careful about what filters apply otherwise the results will not satisfy the brief requirements.

Module 2 allows the user to compare the items (rooms) which are proposed by the first module against three criteria: cost of change, timescale of change and best matching attributes. One way to test which option fits best is to consider the cost of converting the existing room type to the proposal being considered. Cost of changes can be assigned from a database that will contain cost linking data of rooms. The database would contain data that derive from the following procedure: the existing room will have to be checked against all other proposed rooms in terms of refurbishment changes. No actual costs will be provided as detailed costing can only emerge in detailed design, instead a matrix will be created that will contain cost factors among changes of spaces. The matrix can be pre-computed and then the database can be inserted in a BIM platform e.g. Revit though the Revit API. Beyond cost, the second criterion to consider when assessing nominated spaces would be to estimate how much time will take for the refurbishment to be completed.

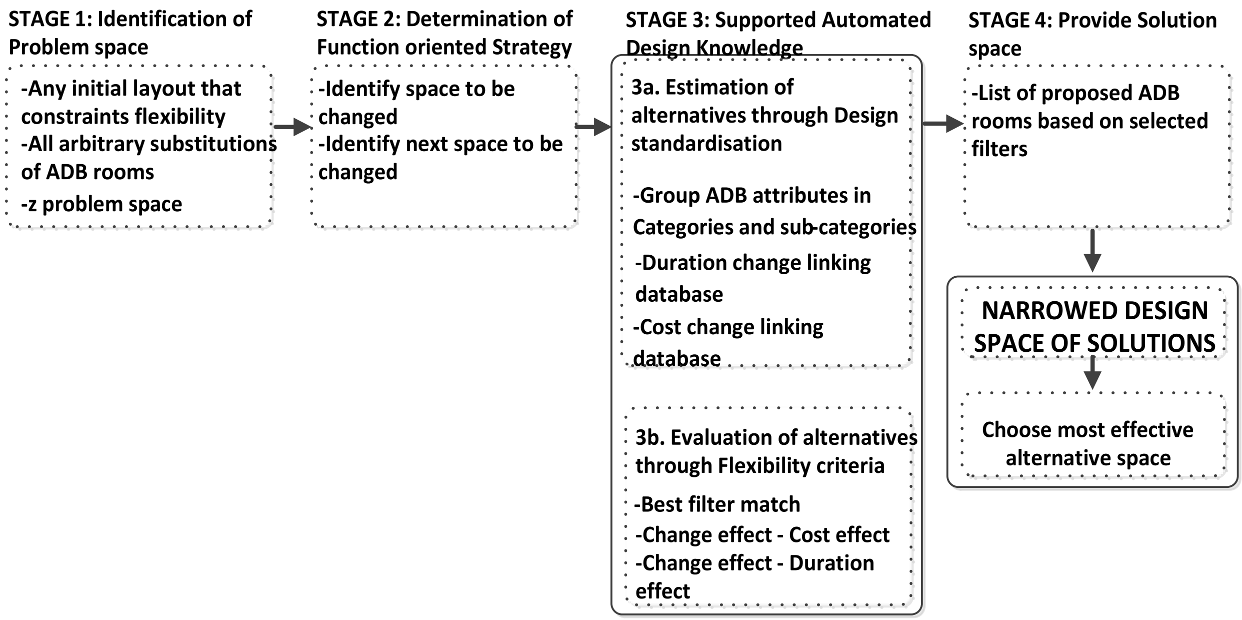

Figure 2: The process of narrowing the design space of solutions in a BIM add-on to the Activity Database (ADB).

As discussed earlier, flexibility is analysed in a change frame format and in a time frame format. Another database can be created therefore to provide knowledge regarding the duration for a change to be completed. The ADB room coding list (Department of Health, 2012) contains information of the room categories and sub categories. These room subcategories are further analysed into room variabilities. The tree map hierarchy of the ADB room coding list will provide the first knowledge about the factors of duration regarding a change. Due to shallow structure of hierarchy a further analysis will be applied, in other words a change will be assigned to one of the three aforementioned types of changes and then further categorised to short, mid or long term change and using First Order Logic the process can be automated. Lastly, the third option to sort out the proposed alternative solutions is by ranking the items regarding how many filters and sub filters are fulfilled. Hence spaces that fulfil all selected filters will appear on a higher rank than spaces that fulfil fewer filters. The proposed Human-Computer Interface experience is based on the principles of the aforementioned theoretical framework.

The first module applies principles/notions/concepts from the function oriented design strategy as described by Fricke (1996), and the need to support knowledge extraction within conceptual and refurbishment design through design standardisation. The second module applies rules from the concept of flexibility (change frame vs. time frame and change frame vs. cost frame).

CONCLUSIONS AND FUTURE RESEARCH

Previous attempts to apply design standardisation and emulate standard design processes failed to provide satisfactory results or have not yet matured to address the problems that emerge during conceptual design. Some designers adopt top-down processes whereas others prefer bottom-up processes (Lawson 2005). Construction projects are becoming more and more complex, and the amount of information the designer is expected to handle is exhausting. Therefore, information extraction becomes more important than ever. This research presents an innovative method to extract spatial information that usually needs to be extracted manually by the practitioner when making design decisions. The proposed design methodology narrows the design space of satisfactory solutions by integrating the concepts of flexibility and design standardisation. This is based on three approaches: consider the cost of making a space change, providing knowledge regarding which alternative space is more cost efficient; consider the duration needed for a change, providing knowledge regarding which alternative space is more time efficient; and provide knowledge regarding which of the proposed alternatives satisfies the most criteria-filters that have been set by the user, based on existing ADB metadata. These three approaches become criteria in the ADB add on for BIM to sort out proposed solutions. These proposed solutions emerge after introducing design standardisation in ADB rooms via extracting the information they contain. This is achieved by automatically identifying common design components and attributes. Finally, the parameter of inserting cost links and timescale duration links within the ADB rooms applies value engineering at the early design stages of the project.

Further on-going research will provide adequate support for the proposed modules. Both aforementioned modules need to be developed and tested in various case studies to evaluate and test their performance. The filter categories need to be justified by the end users. The Engineering Requirements of the filters will be collected through interviews with various stakeholders. Architects specialised in healthcare design, BIM and the ADB plug in will be interviewed in both new and refurbishment projects they participated. Clients will be asked regarding the quality of feedback they would like to receive in the early stages of a project. For the cost database, professionals will be asked about cost refurbishment changes and what procedures they follow to estimate them.

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APPENDIX C

Using BIM to Design Flexible Spaces and Apply Design Standards in Healthcare Facilities[15]

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This paper explored key factors that can enhance the designer`s role when designing space for flexibility with the focal use of building information modelling (BIM) and design standardisation. An exploratory study was conducted using a questionnaire survey. The questionnaire was piloted to a Web-based Group (48 responses) and then it was distributed to the top 100 UK architectural firms (10 responses) based on the Building Magazine, (2010). Both descriptive and inferential statistics were used. The questionnaire survey included both open ended and close ended questions. The paper provides empirical insights about how design standardisation and flexibility can be applied with BIM. It suggests that embedding flexibility can be enhanced with BIM by supporting the generation of different design options and scheduling design tasks with different information attached. The results also showed that strategies such as "adapting," "contracting" and "expanding" are more beneficial than other flexible strategies. Regarding standardisation and flexibility, the results showed that although standardisation is not the panacea of providing flexible solutions, it is indeed applied and applicable in construction projects that require flexibility. The chosen research approach measures, records and reports the perceptions and worldviews of the respondents. Therefore, the research findings are based on how reality is formed by the participants and their experiences. With that in mind, the information identified was used to draw some noteworthy findings that provide detailed information on embedding flexibility in healthcare buildings.

Keywords: Conceptual phase, BIM, flexibility, healthcare design, standardisation.

[15] *Ahmad AM, I Krystallis, P Demian and A Price, 2014. "Using Building Information Modelling (BIM) to Design Flexible Spaces with Design Standards in Healthcare Facilities." Journal of Civil Engineering and Architecture Research, 1(5), 312-326.*

INTRODUCTION

The concept of flexibility in healthcare design is not new. Healthcare buildings are in continuous change, but their future cannot be predicted with a high degree of accuracy [***1***]. Buildings must be seen as a process, being able to meet the ever changing demands of the facility users. There are two practices that can be utilised by owners with dynamic requirements [***2***]. These are:

Scrap and build practices: in this approach, design and construction assumes fixed programmatic requirements. As a result, renovations are expensive when change in use is required. If renovation is not viable, then demolition might be the best solution; and

Stock maintenance practices: in this approach, design and construction emerge by consideration of current requirements and *"provision for unknown future uses and technical upgrading*" [***2***].

The application of stock maintenance practices is continuously increasing over the years in the operational life cycle of healthcare facilities. The INO Hospital in Bern, Switzerland [***2***]; the Addenbrooke's Hospital in Cambridge, UK [***3***]; the St Olav's Hospital in Trondheim, Norway [***4***] and the Health Care Service Corporation Building in Chicago, USA [***5***] are some of the many examples showing that healthcare managers and owners are choosing flexible strategies in order to deal with the ever-changing demands. From these examples, it can be seen that stock maintenance practices are well established in the design and construction process of healthcare projects. Due to the new Government's BIM Construction Strategy plan [***6***]; it is important to understand how these practices should be implemented now that BIM is the default IT platform for the design and construction processes. Both architects and engineers are requested to be BIM-able to a certain level by 2016 in order to operate successfully the on-going rapid technology invented for such complex design problems (healthcare facilities) with other stakeholders. As such, BIM is expected to be adopted by the Architectural, Engineering and Construction (AEC) industry by 2016 [***7***]. Additionally, there is little research regarding the impact of healthcare space standardisation on hospital designs [***8***].

A questionnaire survey was designed to explore key factors that can enhance the designer`s decision-making when designing space flexibility during healthcare refurbishment with the use of BIM. The questionnaire targeted architectural designers with healthcare experience. Literature suggests that design standardisation and BIM as individual concepts can add value to the design of healthcare facilities. Driven by this notion, a hypothesis is framed that designers with healthcare and BIM experience are of the view that the applications of standardisation and BIM can enhance flexible space design. This was tested in linear correlation. The basis of this hypothesis was that novice users will not be able to fully explore BIM whereas experienced users would have identified best practices to achieving more flexible and standardised designs with BIM support.

LITERATURE REVIEW

Towards Flexible healthcare facilities

The Department of Health, [***9***] stated that when a facility is empowered by flexibility an "*annual savings of up to £1.8billion are achievable*". Pommer *et al*., [***10***] stated that "*Hospitals are constantly under construction with on-going renovation and expansion to accommodate new modalities, new protocol, and new technologies*".

Furthermore Gupta *et al*., [***11***] stated that flexibility should be the cornerstone of the design as it allows the facility to grow and expand in cases of building upgrades, and can also change its internal functions. Over the years, many healthcare facilities are becoming obsolete while their lifespan has not reached its peak level. These are mostly caused by changes in demographics, operational running cost, technological hospital demands, operational and functional spaces requiring constant attention over the lifecycle of the facility. Ignoring these factors in a given healthcare facility tends to reduce its functional existence by increasing operational cost causing early re-construction, re-development or large refurbishment. Adams, [***12***] argued that a flexible hospital could be designed today, but be used for a different function in the future. Intelligent spaces that can adapt to growth in population are one of the factors that initiate flexibility in the future. Flexibility is important when adapting to the needs and appeals of healthcare facility users. When a facility adapts to changes, it tends to increase the lifespan of a facility and reduces the need for major refurbishments. It is difficult to predict the future of hospitals with a high degree of accuracy [***3***]. For example, hospital bed numbers should increase in the case of population increment, but the exact population is difficult to be forecasted. Flexibility is viewed as an option that can be switched on or off when required. Therefore, a facility is supposed to be able to expand and increase its number of beds when required. Neufville *et al.*, [***3***] argued that flexibility can improve value for money in hospital infrastructure investment. They also argued that to achieve value in hospitals, contractor-clients relationships should not be encouraged, rather public and private relationships should be motivated to enable long-term partnerships to deliver cost efficiency and shared benefits over the life cycle of a facility. Carthey *et al*., [***13***] described flexibility at a micro and macro level. Micro flexibility can be initiated in a building system within 5-10 years (short-term), while macro flexibility can be achieved within 50-100 years (long-term).

Slaughter, [***14***] discussed the types of changes that may occur. The first depends on the function. In a healthcare facility, such changes may occur when *re-using existing functions* – upgrading an existing space for better performance; *creating new functions* – creating spaces for additional functions; or changing for different functions – *altering the space* for different functions to take place. This spatial transformation will allow the space to adapt to different circumstances. Pati *et al*. [***15***] and Kronenburg, [***16***] among others defined these as adaptable strategies. The second type of flexibility is related to the structural transformation of a building to meet specific performance requirements. For example, to expand the *capacity* of a facility; change in capacity may lead to increment in the building's *volume* and/or *loads*. Transformation is more rigid, it may involve spatial development which includes the structure of a facility. This type of change is more expensive and takes a long time to conduct. The third type of flexibility is related to changes in the building's *flow*. Changes in *environmental flows* may require a change to occur due to a climatic change; change in flow of *people/things* may occur from an organisational change.

Impact of BIM in Design Creativity

Reddy, [***17***] stated that "*BIM provides architects with infinite freedom to showcase their creativity*". Lee, [***18***] stated that the early adoption of BIM increases not only productivity but also creativity in building design process. While Moreira *et al*., [***19***] described that there is a need to examine the influence of BIM tools on design creativity. Creativity and digital technology work alongside each other, but creativity can be achieved through the use of technology as a medium to express imaginative thoughts. The designer is expected to be innovative and creative, while technology empowers the designer to achieve conceptual imaginations at different levels [***20***]. Creativity and BIM can facilitate the ability to embed flexible strategies within a healthcare facility. BIM tools allow design imaginations to be explored in a BIM environment. Some of the benefits when using creativity and BIM are: providing design details of a virtual building using models and simulation to enable stakeholders to understand better the scope of work that needs to be done; allowing the extraction of different views from models; collaborative work; automation; and analysis and evaluation of models to save project time and cost. BIM helps to conduct projects with more confidence and also allows the exploration of the nature and scope of work at the early project stages. Furthermore, Eastman *et al*. [***21***] described that alternative designs can be generated using "*what if"* scenarios with different BIM tools. For example the DProfiler™ can be employed to optimise different design options. Therefore, there is a need to explore the ability of "*what if"* scenarios at different levels such as short-term and long-term levels.

Design Standardisation in Healthcare with BIM

Standardisation means different things to different people in healthcare and BIM literature. In healthcare, standardisation is discussed in various terms. The UK Government and building industries addresses standardisation from many aspects some of them are focusing on procurement methods such the Procure21 and recently the Procure21+ procurement framework which is designed to *"improve the procurement process for publicly funded schemes and create an environment where more value could be realised from collaboration between NHS Client and Construction Supply Chains"* [***22***]. Additionally, the Health Building Notes (HBN) [***23***] is another effort by the DH to identify the best practice standards in the planning and designing phases of healthcare facilities. The series identifies specific and/or service requirements and inform the design and construction teams. Other series of publications have also been released to support best practices. The Health Technical Memoranda (HTM) [***24***] identifies healthcare specific standards for building components as well as the design and operation of engineering services. The Activity DataBase (ADB) [***25***] is another release, this time a software tool that is used as an add-on in BIM platforms and contains information for briefing, design and commissioning for new build and refurbishing healthcare buildings in acute and community settings. Standardised spaces are generally accepted to support process and workflow, and consequently they should improve performance and productivity [***8***]. Reiling, [***26***] stated that with standardisation, processes should be more reliable and simplified; it also reduces reliance on short-term memory and it promotes an average process to be followed by those unfamiliar with the surrounded environment to achieve work safety and efficiency. There is little research evidence relating to the impact of space standardisation and BIM on healthcare delivery. Standardisation is mostly discussed in BIM literature in terms of interoperability, which is concerned with product-model data exchange in project communication. Thus, this study investigates the effect of design standardisation on practitioners who design with BIM products.

METHODOLOGY

The population for the questionnaire survey included architectural firms in the UK and academics in the built environment. The pilot study was conducted first; it was uploaded to the members of a Web-based Group and a total of 48 responses were received. The pilot survey was revised and the main survey was conducted. The main study focused on soliciting the opinion of the top 100 UK Architectural firms based on the *Building Magazine* league table 2010. Out of 100 invitations, 10 responses were recorded.

The aim of the questionnaire survey was to explore the key factors that can enhance the designer`s role when designing space for flexibility in healthcare facilities with the use of BIM. The survey was grouped into four sections: i. background information of the respondents; ii. designing flexible healthcare spaces; iii. standardisation of healthcare space; and iv. flexible space design with BIM. The questionnaire survey targeted respondents such as architectural designers, healthcare planners and BIM users with healthcare experience in the AEC industry. A cross-sectional descriptive survey was designed as the preferred type of data collection as it enables a large set of opinions to be collected in a relatively short time.

Both quantitative and qualitative data were collected, open ended and close ended questions were employed. Open ended questions were analysed by grouping responses into major categories. For example, the respondents were asked to identify spaces that commonly change. Their responses varied from multi bedroom to single bedroom etc. which eventually were grouped under a major category "bedroom". According to the Department of Health [***27***] it is described as Room Coding list. The questionnaire survey respondents were asked to put their answers in a ranking order. Eventually the scores emerged by assigning points to each ranked answer. For instance, the respondents were asked to identify six spaces that change most frequently in a ranking order. The first given answer would get six points, the second gets five points and so on. Close ended questions were employed and respondents were asked to rate their agreement with statements using a five-point Likert scale. Respondents that opted for Highly Effective (HE) and Effective (E) were grouped together to estimate the proportion of *"successes*" of the question in context. The responses were then transformed to interval variables. Interval data *"are considerably more useful than ordinal data*" and *"(t)o say that data are interval, we must be certain that equal intervals on the scale represent equal differences in the property being measured*" [***28***]. As such the difference between each five-level Likert item is the same.

The sample proportion of successes was used to estimate the unknown population proportion. The analysis of the responses involved both descriptive and inferential methods. Due to that the number of successes and the number of failures are not at least 15, a simple practical adjustment first introduced by Edwin Bidwell Wilson in 1927 was employed, the "*plus four estimate*". In short, *"the adjustment is based on assuming that the sample contains four additional observations, two of which are successes and two of which are failures"* [***28***].

Pilot study

Pilot sample: Members of Web based Group.

Relevance of pilot sample to this research: the web based sample was selected due to the diversity of the professionals within the group. There are individual understandings and definitions of BIM from different stakeholders; perhaps it was important to explore the different opinions of stakeholders within the AEC industry. *Who are the webs based sample?* (CNBR) Yahoo group is the Co-operative

Network for Building Researchers; it is a basic mail list for people interested in building research. This group includes professionals such as project managers, architects, contractors, real estate managers, researchers, industry professionals' and so on. Members share news about conferences, journals, vacancies, new books, new findings and so on*. Location of this sample:* it is possible that participants could be from any part of the world, the group is open to all professionals around the world. *The questionnaire survey response from this sample:* there were a total of 48 responses. The questionnaire survey was uploaded on the CNBR Yahoo group website; the total number of people who received the invitation cannot be specified, there are a over 3000 registered members on the website, but only registered members who had set their accounts to receive updates would have seen the link without logging on to the CNBR Yahoo group web page.

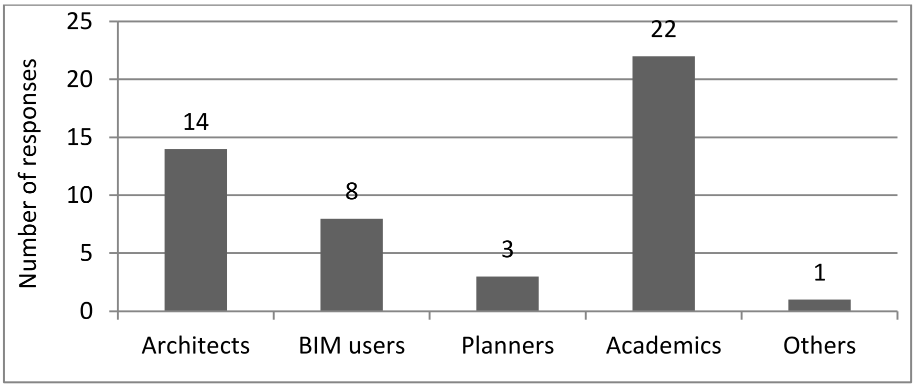

Figure 1: Profession most relates to Web-based Group (48 total).

Figure 1 shows the pilot sample to include architects, BIM users, planners, academics and others; the category *"others"* was also provided to the questionnaire respondents as a space to identify other specific professions, but only one response was recorded.

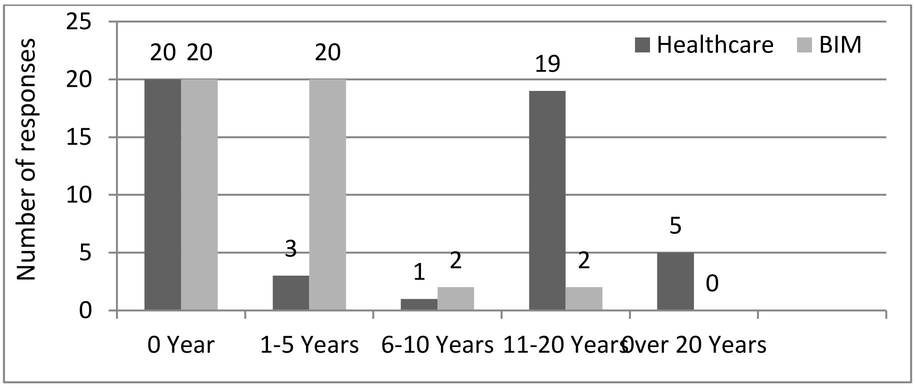

Figure 2: Years of healthcare experience within Web-based Group.

Figure 2 shows the years of healthcare design experience and BIM experience of pilot sample, where 20 (41.6%) of the respondents have no healthcare and BIM experience, 20(41.6%) of the respondents have 1-5 years of BIM experience and 3 (6.25%) of them have also BIM experience, 19 (39.6%) have 11-20 years of experience in healthcare and 5 (10.4%) have more than 20 years of healthcare experience. Lastly, none of the respondents has over 20 years of BIM experience.

PILOT STUDY FINDINGS AND ANALYSIS

Designing flexible healthcare spaces

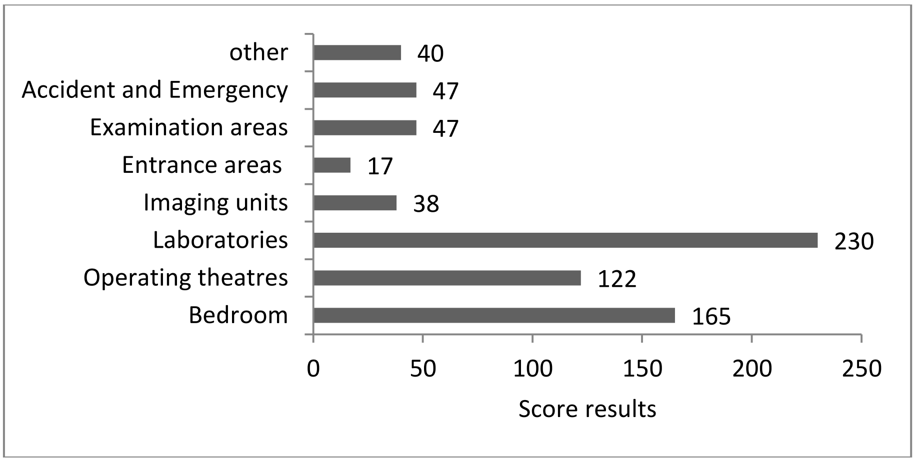

Figure 3: Spaces that frequently change in healthcare facilities (Web-based Group).

The pilot study respondents were asked to rank the spaces that rapidly change in healthcare facilities. Based on the code list for ADB rooms [***27***], the responses were grouped in major categories. For instance, entrance, waiting area and reception area were grouped under the *"Entrance/Reception/Waiting"* category. The questionnaire survey respondents were asked to indicate the spaces that rapidly change in a hierarchy order ranking, with the first choice receiving six points and the last receiving only one point. The results showed that "*laboratories*" are ranked first, followed by "*bedrooms*" and "*operating theatres*" (Figure 3).

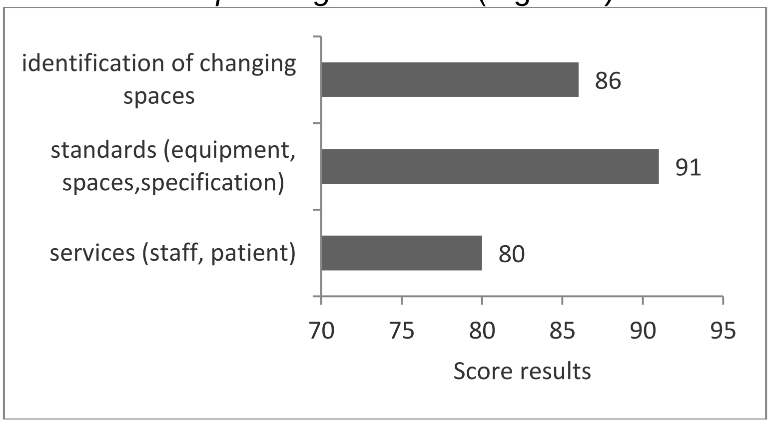

Figure 4: Top three important considerations for designing flexible spaces (Web-based Group).

Similarly, they were asked to identify the top three important considerations for designing flexible spaces (Figure 4). Again, the responses were grouped into categories. The pilot sample ranked "standards" first, "services" second and "identification of spaces" being the third most important. Equipment, standard spaces and specifications were grouped under "standards". Staff and patient needs were grouped under the category of "services". The third important "identification of changing spaces" included quotes-issues such as "suggest spaces for expansion", "categorize spaces for expansion", "allow reasonable spaces for expansion", "identify spaces that could expand", and "highlight spaces that are expected to change in the future".

Table 1 shows the ranking of the effectiveness for the different flexibility concepts. It was estimated with 95% confidence that between 78.1% and 96.9% of the population would rank "*modular design*" first. "*Flexible furniture/equipment*" was ranked second with 95% confidence between 60.3% and 85.5% and lastly, "*shell* *space*" was ranked third, with 95% confidence that between 53.3% and 80.0% of the population would find the aforementioned concept HE/E. A complete view of the respondents' choice and the 95% confidence intervals of the population are given in Table 1.

Table 1: Confidence intervals for pilot sample on the effectiveness of the following flexibility concepts.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
Modular design	0.969	0.781	0.875
Shell space	0.800	0.533	0.667
Flexible curtain walls	0.578	0.297	0.438
Flexible furniture/equipment	0.855	0.603	0.729
Multipurpose foundations	0.535	0.132	0.333
Flexible partitions/internal walls	0.884	0.325	0.604

Standardisation of healthcare space

The respondents were asked to rate their agreement with three statements regarding how standardisation affects the concept of flexibility. The general impression is on the positive side that standardisation does not necessarily hinder flexibility in healthcare spaces. The respondents did not significantly support any of the three given statements (Table 2) and the agreed proportions were significantly low. Specifically, it was estimated with 95% confidence that between 23.8% and 51.2% of the population would believe that standardisation "*creates rigid spaces/layout*". The rest of the statements were rated even lower, which gives the notion that the population would believe standardisation does not impede flexibility.

Table 2: Proportions and confidence intervals for pilot sample on standardisation impeding flexible space opportunities.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
Creates rigid spaces/layout	0.512	0.238	0.375
Produces interrelationships of spaces that are highly complex	0.444	0.181	0.313
Hinders modularity layout concept	0.219	0.031	0.125

Flexible space design with BIM

The following questions refer to the role of BIM and how effective or ineffective it can be when designing flexible healthcare spaces. In Table 3 the respondents were asked to state the level of effectiveness of using BIM for analysing and evaluating flexible healthcare spaces to inform decisions on two scenarios: for short-term and long-term basis. The results are not satisfactory enough to conclude that BIM is effective or ineffective in informing decisions on short term or long term basis.

Table 3: Proportion and confidence intervals for pilot sample for the effectiveness of using BIM for analysing and evaluating flexible healthcare spaces to inform decisions.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
Short-term basis	0.641	0.359	0.500
Long-term basis	0.703	0.422	0.563

The respondents were asked to rate their agreement within two scenarios (short-term or long-term basis) regarding the effectiveness of using "what if" scenarios with BIM in the design of flexible healthcare spaces. The results (
Table 4) look quite close to the previous question. The responses cannot provide a positive opinion whether "what if" scenarios can provide a positive impact on the design of flexible healthcare facilities.

Table 4: Confidence intervals for pilot sample on the effectiveness of using "*what if"* scenarios with BIM in the design of flexible healthcare spaces.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
Short-term basis	0.641	0.359	0.500
Long-term basis	0.703	0.422	0.563

The respondents were then asked to state their degree of agreement that BIM tools hinder design innovation and creativity. The results showed that the population would believe BIM tools hinder innovation and creativity. The population's agreement is between 60.3% and 85.5% with 95% confidence. Finally, the respondents were asked to rate the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility space in the following design strategies: "expanding", "contracting", "relocating" and "adapting". The respondents found BIM HE/E in three out of four concepts, and it was estimated that the population between 60.3% and 85.5% with 95% confidence would believe BIM is effective. "Adapting" was chosen the least strategy that is benefited by BIM (48.8%-76.2% with 95% confidence). The 95% confidence intervals for all strategies are given in Table 5.

Table 5: Confidence intervals for pilot sample on using BIM for analysing, evaluating and modelling flexible healthcare facility space strategies.

Web-based Group	**95% confidence interval results**		
	Upper limit	Lower limit	Sample proportion
Expanding	0.855	0.603	0.729
Contracting	0.855	0.603	0.729
Relocating	0.855	0.603	0.729
Adapting	0.762	0.488	0.625

Discussion of findings for pilot sample

Even though the pilot study was not the main study, some helpful conclusions can be drawn. Design standards have been characterised as the most significant consideration when designing flexible spaces which was further supported by the

disagreement that standardisation impedes flexible design opportunities. Also the importance of “identifying spaces that rapidly change” was highlighted as a noteworthy factor that needs to be considered. The results were less conclusive regarding the effectiveness of BIM in certain tasks such as to use BIM for analysing and evaluating flexible healthcare spaces for short-term or long-term basis, and to use BIM for “what if” scenarios. This uncertainty of survey results on whether BIM is effective can be explained by the background information that 50% of the respondents have no experience of BIM which eventually limits the conclusions that could be drawn regarding BIM.
The questionnaire survey was presented in two different formats. These include an online web link and MS word document. After the pilot study, this research further explored findings from architectural firms. Findings from the pilot study showed that some of the questions were left unanswered by the respondents. Therefore, during the main study some questions were omitted, while others were refined. Further information was provided in the “more information” section on the online questionnaire survey and the definitions of key issues in question such as flexibility, standardisation and BIM were presented in the beginning of each section of the questionnaire survey presented in MS Word format.

MAIN STUDY

Main sample: Top 100 UK architectural firms based on the *Building Magazine,* 2010. To draw a representative sample, the quota sampling method was chosen [***29***]. The research interest is on UK Healthcare facilities. Therefore, only architectural firms that are based in the UK were considered. Next, the experts’ opinion on design knowledge in terms of flexibility and design standardisation was measured. Architects with experience in the field of healthcare design were questioned. The top 100 UK architectural firms ranked by *Building Magazine*, (2010) were chosen which was based on the highest number of UK chartered architects within UK firms. They were selected for their practical experience in the design of buildings in and outside the UK as described by *Building Magazine,* (2010). The architectural firms contacted for the purposes of this research were UK based and most of the architectural firms have international offices around the globe. Therefore, with both UK and international architectural working experience, the participation of such firms would provide robust practical data that this research can analyse and evaluate. All of the aforementioned firms were contacted; out of the 100, only 10 architectural firms responded (10%).

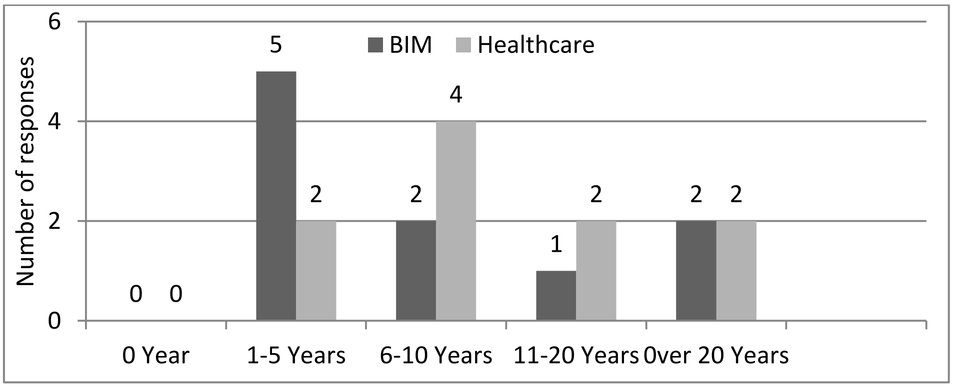

Figure 5: Years of BIM and Healthcare experience within main sample.

Background information

Figure 5 presents the years of healthcare and BIM experience for the main sample. The level experience in this sample is spread across different frames which gives a variety of experience in the two fields of interest. Based on the collected background information, inferential tests were applied to estimate the population's beliefs and to test the aforementioned hypothesis. The sample can be classified as a good sample for exploring the application of BIM in healthcare facility design, as healthcare design experience is satisfied and also the sample is experienced in the application of BIM. Over 50% of the sample has over 10 years of both healthcare and BIM experience. But it is noteworthy to understand that the sample is small.

ANALYSIS OF QUESTIONNAIRE FINDINGS

Designing flexible healthcare spaces

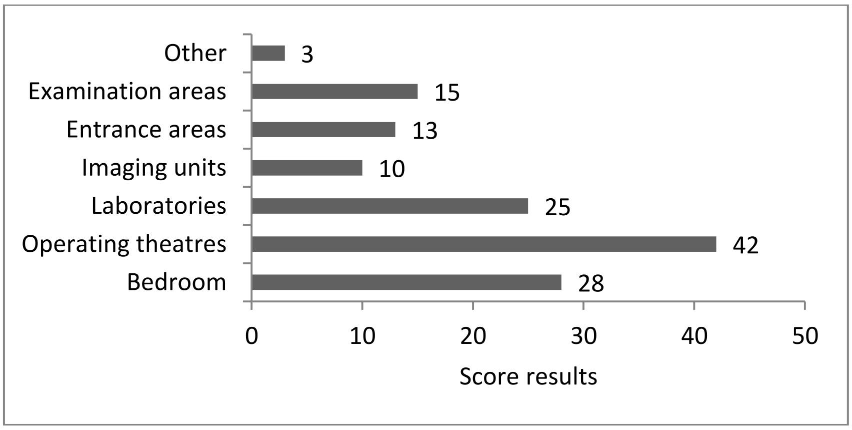

Figure 6: Spaces that frequently change in healthcare facilities.

Regarding which spaces are most likely to be altered in healthcare facilities, the main sample ranked "operating theatres" as the first space that frequently needs to be changed, followed by "bedrooms" in second place and "laboratories" in third place. The same procedure for ranking the responses was used for the pilot study. The complete ranked spaces are presented in Figure 6. It is noteworthy to understand that the same three categories were identified by the Web-based group but in a slightly different order.

Figure 7: Top three important considerations for designing flexible spaces.

The main sample ranked "standards" as the first most important consideration for designing flexible spaces, followed by "services" and "cost". Unlike the pilot sample, the main sample suggests “cost” as an important factor that needs to be considered in the design stage (Figure 7). The degree of effectiveness of six flexibility concepts is presented in Table 6. Three flexibility concepts “modular design”, “shell space” and “multipurpose foundations” were rated equally HE/E and with 95% confidence that between 67.4% and 100% of the population would believe these three concepts are HE/E.

Table 6: Proportions, 95% confidence intervals and Spearman’s rho on degree of effectiveness regarding specific flexibility concepts.

Main sample	95% confidence interval results			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Modular design	1.000	.674	.857	-.467	.180
Shell space	1.000	.674	.857	-.082	.431
Flexible curtain walls	.951	.478	.714	-.140	-.629
Flexible furniture/equipment	.894	.392	.643	-.018	-.204
Multipurpose foundations	1.000	.674	.857	-.612	-.157
Flexible partitions/internal walls	1.000	.571	.786	.063	.179

Furthermore, correlation tests did not show any strong evidence that designers with experience in healthcare or in BIM tend to find more effective one concept of flexibility over the other (Table 6). Further correlation tests between the six flexibility concepts revealed that there are strong correlations among the concepts: “*flexible partition*”; and “*shell space*” (r_s(10)=.913, p.000); “*flexible partition*” and “*flexible furniture*” (r_s(10)=-.922, p=.000); and finally, “*flexible furniture*” and “*shell space*” with (r_s(10)=-.866, p=.001). A detailed list of the analysis results is shown in Table 7.

Furthermore, this study explored the opinion of architects about standardisation impeding flexible space opportunities by providing specification that could: produce rigid spaces/layout; produce interrelationship of spaces that are highly complex; or hinders modularity concept layout. There is a need to explore the application of standardisation in flexible healthcare spaces to achieve added value, cost effectiveness and cost efficiency [***8***].

Table 7: Correlation tests for various flexibility concepts.

			Modular design	**Shell space**	**Flexible curtain walls**	**Flexible furniture**	**Multi-purpose foundation**	**Flexible partition**
Spearman's rho	Modular design	Correlation Coefficient	1	.764*	-0.375	-.661*	0.218	.697*
		Sig. (2-tailed)		0.01	0.286	0.037	0.545	0.025
		N	10	10	10	10	10	10
	Shell space	Correlation Coefficient	.764*	1	-.764*	-.866**	0.048	.913**

	Sig. (2-tailed)	0.01		0.01	0.001	0.896	0
	N	10	10	10	10	10	10
Flexible curtain walls	Correlation Coefficient	-0.375	-.764*	1	.661*	0.327	-.697*
	Sig. (2-tailed)	0.286	0.01		0.037	0.356	0.025
	N	10	10	10	10	10	10
Flexible furniture	Correlation Coefficient	-.661*	-.866**	.661*	1	0.082	-.922**
	Sig. (2-tailed)	0.037	0.001	0.037		0.821	0
	N	10	10	10	10	10	10
Multipurpose foundation	Correlation Coefficient	0.218	0.048	0.327	0.082	1	-0.174
	Sig. (2-tailed)	0.545	0.896	0.356	0.821		0.631
	N	10	10	10	10	10	10
Flexible partition	Correlation Coefficient	.697*	.913**	-.697*	-.922**	-0.174	1
	Sig. (2-tailed)	0.025	0	0.025	0	0.631	
	N	10	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Standardisation of healthcare spaces

Most of the respondents agreed that standardisation could affect flexibility in all three categories "*some of the time"* (Figure 8). It was estimated with 95% confidence that between 64.0% and 100% of the population would believe that standardisation hinders modularity layout concept which is the strongest probability among the three statements. The statement that standardisation "*creates rigid spaces/layout*" was ranked second (with 95% confidence between 47.8% and 95.1%) and "*produces interrelationships of spaces that are highly complex*" was ranked third with significantly low probability (with 95% confidence between 31.2% and 83.1%).

The responses for each of the three statements were tested against the years of BIM experience as well as the years of healthcare experience the respondents had. There is no strong evidence to suggest that there is a linear correlation that architects with experience in healthcare or in BIM tend to agree that standardisation impedes flexibility in any of the three statements. The 95% confidence intervals for the population and the spearman's coefficient are presented in Table 8.

Flexible space design with BIM

The results suggest that BIM is effective for both short-term and long-term analysis and evaluation of flexible healthcare spaces with 95% confidence that between 57.1% and 100% of the population would believe BIM is HE/E on a short-term basis. While 67.4% and 100% of the population would believe BIM is effective on long-term basis. Spearman's tests revealed that there is strong degreasing linear correlation ($r_s(10)=-.633$, $p=.049$) for the respondents with high BIM experience that believed BIM is effective to inform decisions on short-term basis.

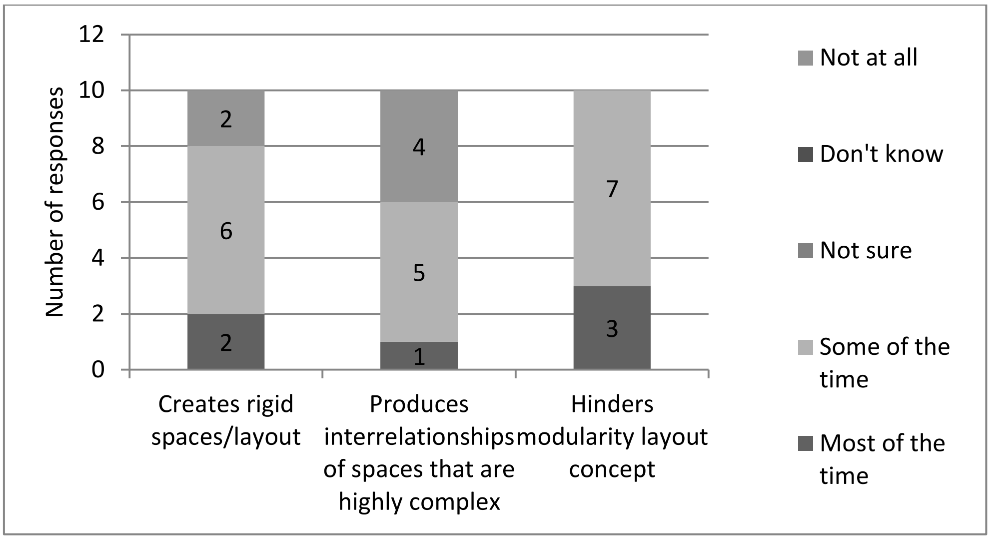

Figure 8: Opinion of respondents on standardisation impeding flexible space opportunities.

Finally, no evidence suggests that designers with more experience in healthcare or BIM find BIM more effective for analysing and evaluating flexible spaces on long-term basis. Detailed results are presented in Table 9.

Table 8: Proportions, 95% confidence intervals and Spearman's rho on standardisation impeding flexible space opportunities.

Main sample	**95% confidence interval results**			**Correlations**	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Creates rigid spaces/layout	.951	.478	.714	.384	.000
Produces interrelationships of spaces that are highly complex	.831	.312	.571	.119	.156
Hinders modularity layout concept	1.000	.640	.857	.204	-.157

Next, the respondents were asked to rate the effectiveness of using "*what if*" scenarios in the design of flexible healthcare spaces on the same two decision foundations: short-term and long-term basis. It was estimated with 95% confidence, that between 23.8% and 76.2% of the population would find effective the use of "*what if*" scenarios on a short-term basis. On the other hand, between 67.4% and 100% of the population would find "*what if*" scenarios effective on a long-term basis. Finally, the Spearman's tests did not show any significant level of linear correlation between the respondents rating of the effectiveness of "*what if*" scenarios and the years of experience in healthcare or BIM (Table 10).

Table 9: Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing and evaluating flexible healthcare spaces to inform decisions on short term and long term basis.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis	1.000	0.571	0.786	-0.633*	0.304
Sig. (2-tailed)				.049	
Long-term basis	1.000	.674	.857	-.326	.157

*. Correlation is significant at the 0.05 level (2-tailed).

The respondents were then asked to agree or disagree that BIM tools hinder design innovation and creativity (Table 11). The results showed that the population would believe BIM tools hinder innovation and creativity "*all the time*" (57.1%-100% with 95% confidence). Spearman's tests revealed there is strong degreasing correlation ($r_s(10)=-.638$, $p=.047$) for the respondents who Strongly agree/agree that BIM tools hinder design innovation and creativity *"all the time"* with experience in healthcare design.

Table 10: Proportions, 95% confidence intervals and Spearman's rho on the effectiveness of using "*what if*" scenarios with BIM in the design of flexible healthcare spaces.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Short-term basis	.762	.238	.500	-.148	.204
Long-term basis	1.000	.674	.857	.490	.039

Table 11: Proportions, 95% confidence intervals and Spearman's rho on the degree of dis (agreement) that BIM tools hinder design innovation and creativity.

Main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
all the time	1.000	.571	.786	.133	-.638*
Sig. (2-tailed)					.047

*. Correlation is significant at the 0.05 level (2-tailed).

In the last question, the respondents were asked to indicate their opinion about the effectiveness of using BIM for analysing, evaluating and modelling flexible healthcare facility spaces. The given strategies were "expanding"; "contracting"; "relocating"; and "adapting". The responses vary and this can be seen on the relative low proportions in Table 12. The analysis showed that the population would believe that BIM is likely to benefit more projects that focus on "*expanding*" and "*contracting*" (23.8%-76.2% with 95% confidence) over projects that focus on "*relocating*" (0%-44.8% with 95% confidence) and "*adapting*" (1.6%-58.4% with 95% confidence). Regarding the Spearman's correlation tests, there is no significant linear correlation concerning the applied flexibility strategies and the years of experience the respondents have in BIM or in healthcare.

Table 12: Proportions, 95% confidence intervals and Spearman's rho on using BIM for analysing, evaluating and modelling flexible healthcare facility space strategies.

main sample	95% confidence intervals			Correlations	
	Upper limit	Lower limit	Sample proportion	BIM experience	Healthcare experience
Expanding	0.762	0.238	0.500	-0.148	0.204

Contracting	0.762	0.238	0.500	0.004	-0.207
Relocating	0.448	0.000	0.200	0.118	0.284
Adapting	0.584	0.016	0.300	-0.131	-0.596

CONCLUSIONS AND FUTURE RESEARCH

The study's key findings regarding the three major fields of interest are presented below.

Designing flexible spaces: this research can conclude that the three types of changes identified by Slaughter [***14***]: spatial, flow; and structural are features of a rapid changing space, but if one asks what spaces are these in a healthcare facility, what would be the answer? Both samples identified *"bedrooms"*, *"Operating theatres"* and *"laboratories"* as the top three categories of spaces that are frequently subjected to change. Both samples identified *"standards"* as the most important consideration for design flexible spaces. Under standardisation hinders the knowledge of equipment specification and the type of room to be applied in a healthcare facility and so on. Another concept that was ranked as important was *"services"* which calls for identifying practices and operations required by facility users (staff and patients) at early design stages during the project's lifecycle; information regarding standards and services is included in ADB. The functional services required define the type of MEP services desirable for the functional space design. Lastly, the main sample identified *"cost"* as an important consideration for the early design stage of a project. One effective method in construction management centred on cost is *Target value design*. The analysis also highlighted that designers find *open building* principles (shell space) highly effective; they also found *adaptability* strategies such as *"flexible partitions"* and *"flexible furniture"* highly effective.

Standardisation of healthcare spaces: The respondents' agreed that standardisation is not the panacea for designing flexible healthcare spaces and this is shown in Table 8 where the 95% confidence intervals showed a very strong probability with 64.0%-100% of the population were of the view that standardisation "*hinders modularity layout concept*". On the other hand "*modular design*" was ranked first among other flexibility concepts in Table 6. Modular design supports standardised units or standardised dimensions to support construction [***30***]. Modular design or prefabrication is described as an advanced construction technology that allows a building to be flexible at a short notice while keeping cost as a primary concern. In Addenbrooke's Hospital, the use of such methods was applied and significant time efficiency was noted [***3***]. As a design principle, both samples agreed that *"modular design"* is a preferable choice for dealing with flexibility.

Flexible space design with BIM: the respondents were of the view that the use of BIM is effective in the design of flexible spaces on both long-term and short-term plans. Within the two bases of application, the respondents were of the opinion that BIM is exploited on a higher rate with regards to *"long-term basis"* concerning the design of healthcare facilities (see Table 9 and Table10). Regarding the use of a flexibility strategy with BIM, the results showed that strategies such as "*contracting*" and "*expanding*" are more beneficial than strategies such as "*adapting*" or "*relocating*". Conversely, the respondents identified *adaptability* and *open building* as the most effective strategies for approaching flexible space design. Comparing these findings; it can be concluded that BIM as a process and a technology should provide improved applications to meet users` demand in regards to the application of *adaptability*.

Regarding the hypothesis, experienced designers with healthcare and BIM experience were of the view that standardisation and BIM can enhance flexibility. The analysis did not provide clear evidence that there is a linear correlation. Further correlations tests revealed that there is strong correlation between two flexibility strategies: *open building* and *adaptability*, since respondents who chose *“shell space”* also chose *“flexible furniture”* or *“flexible partition”.*

The aim of this preliminary study was to articulate the opinion of designers with healthcare and BIM experience on how satisfactory is design standardisation and BIM to accommodate flexible healthcare spaces. The study is essentially exploratory in nature, with a small but experienced sample. Hence, the findings should be considered with attention. Future research should consider possible methods of integrating standardisation and flexibility within a BIM environment. This will offer explorations in Human-Computer Interaction for new design practices. Another gap that was identified is the need for design guidelines that will focus on the application of conceptualising the design of flexible healthcare facilities with BIM. The guidelines should consider: identifying spaces that frequently change; design standards that should be employed in order to apply flexibility; applications that could allow explorations of “*what if*” scenarios and “*design options*” with BIM; and the evaluation methods within BIM that would test those scenarios.

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APPENDIX D

Future-proofing Governance and BIM Capabilities for Owner Operators in the UK[16]

Ilias Krystallis[1], Vasileios Vernikos[1], Sam El-Jouzi[1] and Pete Burchill[1]

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Owner Operators are managing and maintaining their infrastructure assets. In addition depending on the national economic activity, they are being reactive or proactive in their response against uncertainty. Findings from this study showed that improvements can be achieved if the concept of future-proofing of assets -as a structured approach against uncertainty- becomes more explicitly defined. Future-proofing is the process of taking security measures against uncertainty and being proactive throughout the entire project and asset lifecycle. In combination with Information management these should ensure Asset Management (AM) strategies and thus the assets will be responsive to a number of future changes in requirements. In this context, it is asserted that both future-proofing and BIM suffer from a dearth of identification in the context of AM. Through a case study this paper presents an approach to FP at strategic level. Furthermore, governance agendas for FP and BIM capabilities for future-proof information have been identified which Owner Operators and the supply chain can find useful.

Keywords: Information Technology, Project management, Infrastructure planning

[16] *Krystallis, I., Vernikos, V., El-Jouzi, S. and Burchill, P., 2016. Future-proofing governance and BIM for owner operators in the UK. Infrastructure Asset Management, 3(1), pp.12-20.*

INTRODUCTION

Future-proofing (FP) is discussed as a key issue in the pursuit of sustainable assets. Owners are seeking other ways to overcome the financial crisis by investing in the application of the sustainability agenda; and for an asset to achieve sustainability the supply chain recognise that it has to be also future-proofed (Krygiel & Nies, 2008). Policy makers are defining what FP means for the good operation of services (DH, 2013). In this context, the Department of Health defined FP as strategic planning that responds to future changes in requirements, change of use, organisational strategic perspectives, national policy and changing climate. For infrastructure projects, Masood et al (2013) defined FP as “the process of incorporating future developments while changing from an unplanned and uncontrolled state to a planned and controlled state of a resilient infrastructure asset or product service system with minimal negative consequences”. For the purposes of this paper and summarising the above, FP can be defined as a proactive planning and management initiative and process employed by Owners and the supply chain for mitigating risks found in Asset Management which acts as an urgent need against uncertainty. Ultimately FP helps Owners make better decisions during the asset life and creating ways to reduce the effects of problems arising in future events.

To investigate in more detail how FP is applied within an enterprise we observed a major infrastructure Organisation. The observed Organisation manages to allocate public funding through two main streams. The two streams operate as separate entities within the Organisation but ensure good communication exists between them. Within an Owner Operator there are in general two key categories of investment:

- Those delivered through Capital Projects; and

- Those delivered by the Operation and Maintenance teams through their ongoing Operations and Maintenance (O&M) processes.

The Infrastructure Asset Management teams are responsible within the Owner Operator’s portfolio management agendas for owning and maintaining their asset portfolio. The Capital Projects schemes are generally focussed on delivering large investment programmes for new sections of infrastructure, driven by need for capacity enhancement. These schemes are typically implemented from phases Inception to Handover. On the other hand, Operations and Maintenance schemes are delivered through a variety of mechanisms, such as a variety of contracts (lump sum or DBFO) and also by a variety of stakeholders (Joint ventures or in house teams)

Considering the above, Building Information Modelling (BIM) should be the vehicle that progresses such discussion through its structured information management processes. Various Governmental initiatives have been formed globally aiming to introduce BIM to the industry and promote guidance for all disciplines involved in building and infrastructure projects (CORENET 2015; National Institute of Building Sciences 2015; OpenBIM 2013). In an information context, Information futureproofing can be defined as “the process to ensure that required information is retrievable (reusable) throughout the whole lifecycle of infrastructure assets or product service systems when needed” (Masood, et al., 2013).

The UK Government is also promoting the BIM initiative (Cabinet Office, 2011). The perception is that cost efficiencies can be realised by use of a ‘single collaborative source of truth’ (BSI, 2007) during the design phase, through construction, commissioning and into its day to day operation where the end goal is the whole-life management of an asset (BSI, 2014).

The Government Construction Strategy’s 2025 (HM Government, 2013) overarching target is to achieve a “reduction in the initial cost of construction and the whole life cost of built assets by 33%”. To achieve this goal, the Government plans are to ensure funding for key infrastructure projects of up to £9.5bn in rail, aviation and roads and reduced embodied carbon in infrastructure projects. The UK industry has successfully delivered some of the globe’s largest infrastructure and regeneration projects (i.e. Crossrail and London 2012).

There are a number of different BIM definitions floating around. For the purposes of this study we distinguish BIM as:

Building Information Modelling (as a verb) is the process of generating and managing component data within an integrated database and parametric model throughout the project’s Design-Build-Operate lifecycle.

A *Building Information Model* (as a noun) is a digital representation of all physical and functional characteristics of a facility or site serving as a shared knowledge resource for information about the assets. This knowledge database forms a reliable basis for information exchange and decisions during a project's lifecycle from inception onward.

However, to break it down to the two primary features, BIM consists of:

- Geometry – Where is it? How long is it? How tall is it? What is it close to?; and
- Data – What is it called? What is it made of? Does it need any power? Does it have a warranty?

These form the core of what the government considers to be the BIM Deliverable, with traditional documentation such as drawings and reports continuing to be delivered at the same juncture (Figure 1). With BIM there are now robust methodologies (BSI 2007; BSI 2013) that articulate in detail the requirements and approaches for producing a Project Information Model.

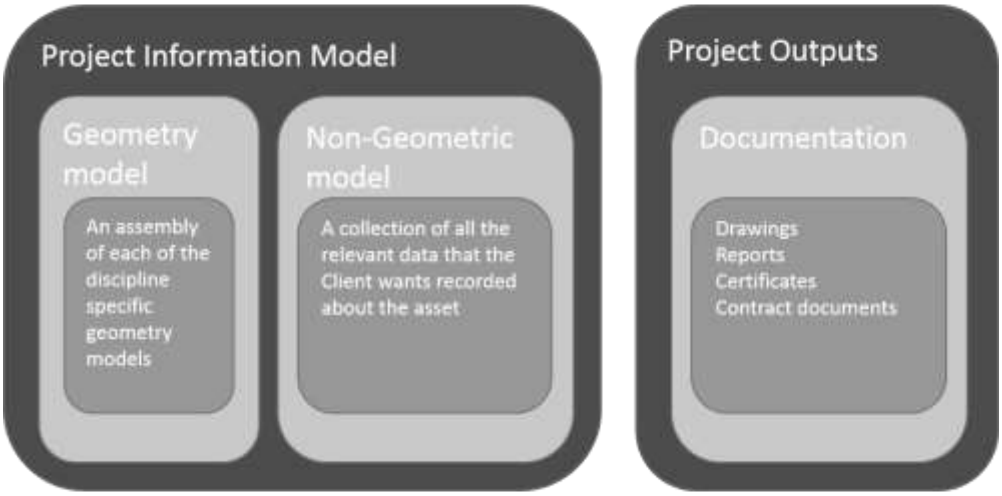

Figure 1: Project Outputs from a BIM Project.

There is a trend within the construction industry that considers BIM to be a new ‘autonomous and detached’ solution for asset management (Pocock, et al., 2014). This is primarily driven by the lack of existing asset data for many projects and a robust set of standards around data recording and delivery. In addition, there seems to be a lack of systematic guidance around future-proofing and how much assets are change-ready to accommodate future changes. Considering the above, there needs to be a distinction made between the role of BIM and the mechanisms that ensure delivery of future-proof assets at pre-handover stages with respect to the lifecycle maintenance and management of assets. There then needs to be an understanding of the synergies between the two and how they can be managed to assist Asset Owner Organisations.

METHODOLOGY

The chosen research methodology of this study was case study. The investigated Owner Operator is a government owned company which manages major linear infrastructure assets. The Organisation operates in the UK and has more than 3500 employees. The study focused on investigating strategic decision making aimed to address uncertainty in Asset management from the early stages. Combined data collection methods took place over a three month period as they deemed necessary to provide a deeper understanding of the research problem. A combination of collective instruments was adopted, and thus, one to one interviews, telephone interviews, group interviews and processes review took place alongside a collection of archived documents that complemented the review process. The case study details are summarised in Figure 2. In the following sections, an overview of the observed challenges from the case study findings is presented.

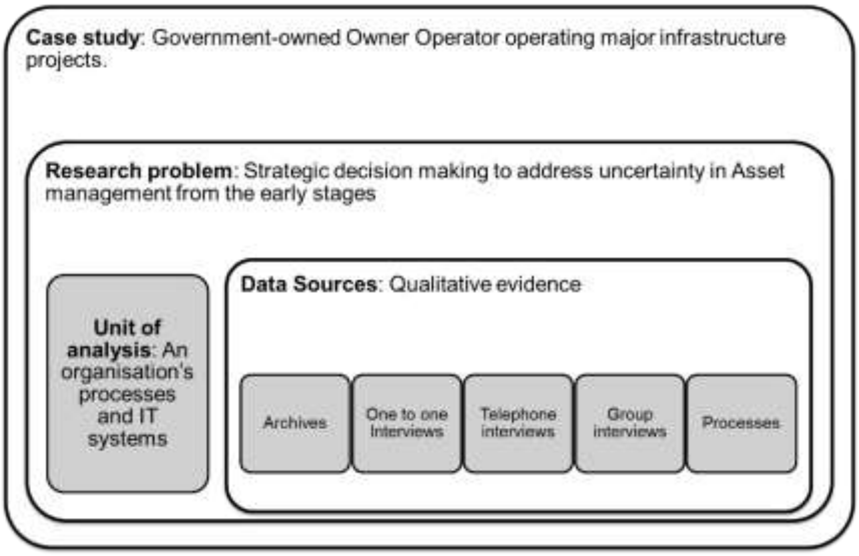

Figure 2: Case study overview.

RESULTS

The future-proofing approach includes the tools and processes to deliver future-proof projects using BIM. The approach is conceptualised into three levels within an organisation (Krystallis, 2016):

Vision: the organisation defines what future-proofing means for the business, and informs the stakeholders and the supply chain about the vision of the organisation to satisfy future-proofing goals as well as adoption of innovative technologies and processes.

Strategy: the strategy involves the identifications of future-proofing governance considerations across three agendas, Government, Strategy and Information management agenda. Each agenda helps the business to explicitly define future-proofing and Information management and further refine in more detail what both concepts mean within the business processes.

Implementation: the last level covers how to apply future-proofing and BIM strategies at project level. It identifies the synergies of FP and BIM across a project's lifecycle and showcases the strengths of using BIM in a FP framework (Krystallis, et al., 2016).

Due to limitations, only the Strategy level is covered in this paper.

Future-proofing governance considerations per agenda

To showcase how a mutation cycle (discussed below) can be initiated, the following emergent themes have been identified and are presented into two main categories, namely FP governance considerations across three agendas and the capabilities BIM can offer around FP solutions. For successful asset management and delivery of future-proofed assets, a formal FP process needs to be formalised. This process depending on agenda varies in terms of what needs to be considered. The three high-level identified agendas are outlined here:

Government agenda: includes actions for both FP and BIM and works as a controlling and supporting mechanism that ensures Clients and the supply chain are working together for the delivery of future-proof assets.
Strategic management agenda: includes decisions the Clients are taking with the support of the supply chain. These decisions are about obtaining assets with the best possible change-readiness incorporated throughout their lifespan.
Information management agenda:
includes processes and support from technology the *supply chain needs to adopt in order to deliver the goals and aspirations set by their Clients.*

Government agenda

With regards to FP, there are two actions that could to be pushed further by the Government:
Future-proofing actions: actions that will allow the Government to monitor and support the Owner Operators obtain future-proof assets. For this to be done there is a need to foster Organisations into creating mechanisms and processes that will support and enhance FP. The following actions have been identified:

- Include contractual requirements that will further support the delivery of FP solutions;
- Establish a FP ranking system where each project/asset can be mapped against its FP capability on a national level; and
- Support Organisations into developing their FP KPIs.

BIM actions: the second action in this agenda should consider how to use BIM processes with regards to FP. The following actions have been identified:

- Many Clients are now focusing on implementing their BIM standards and are starting to understand what BIM and its outputs could mean to them. There needs to be a central control by a Government body that will ensure these standards are sharing common principles. This can be proven to be highly effective for all Asset Owners regardless of sector as quality assurance standards and high quality BIM services across all markets, sectors and projects will be ensured;
- Case studies that showcase evidence, lessons learnt and KPIs achieved from using BIM best practices for future-proofing Asset Management; and

- Guidance and support on how to approach BIM to ensure future-proofing of information and what aspects of BIM can better support FP solutions and processes.

Strategic management agenda

On the delivery side, the Clients need to work with their supply partners to agree over a common strategy on how change-ready assets should be delivered. The following decisions will support this goal:

Strategic decisions: these are decisions which ensure the Clients' goals are clearly communicated to their suppliers. From the suppliers' side there is a need to ensure that the Clients' requirements are addressed. The following will support strategic decisions around FP:

- Future-proofing objectives are ingrained into Plan of works flows;
- The Clients do not focus solely on capital cost but support the supply chain to deliver projects where design life is priority;
- The Change-readiness framework (discussed below) is considered at the early stages of the project;
- Change of mind-set which considers 'payment by results' the only justifiable driver when discussions around future changes / upgrading emerge. Clients are starting to realise that upgrading of services / upskilling of resources is as important as increase of customers service provision;
- The clients should incentivise their suppliers to deliver projects where whole-life cost is reduced as opposed solutions that are targeted for lower capital cost; and
- Clear clarification of future-proofing goals. For instance the Clients should have clear understanding of where they want to have future-proofing feed in within their assets. It is uneconomical to have as a requirement an asset which should be 100% future-proofed, as this is unrealistic and can also be an expensive solution.

Cooperative decisions: these type of decisions are supportive to the strategic decisions described above. These decisions highlight the need for a change in behaviour during decision making. For example, the delivery teams can adopt a more ‘considerate’ behaviour regarding the Asset Management teams. The below can support this:

- During design and construction delivery, if the teams identify that there are areas within the asset that could be considered to be ‘problematic’ in the near future, they should highlight this and try to find solutions that will overcome the issue rather than leaving it to be dealt by someone in the future;

- Decisions should be given by all stakeholders, i.e. the teams that will eventually manage the assets should be invited at the early stages and share their knowledge. As this may rise conflicting interests, there is also a necessity that decisions should be based on pre-agreed weighted criteria;

- The supply chain should bring lessons learnt from other projects regarding the application of best practice in FP.

Information management agenda

Information management has now become an integral part of project delivery. BIM consists of processes around information management and further these are aligned to traditional project management processes. Furthermore, Information management consists of processes that heavily rely on the support of technology.
Implementation processes: to efficiently deliver data that can be used for future-proofing the following should be considered:

- The presence of Employers Information Requirements (EIR) as a contractual document that outlines information contractual deliverables is becoming more and more present in the contractual agreements for new projects. As part of the EIRs, there is a need that Asset information needs are clearly defined to ensure asset data will be produced for efficient AM;

- During the maintenance cycle, EIRs may not be relevant as in most cases design is not required. Therefore, only Asset Information Requirements need to be developed. These requirements identify which assets are maintained and are updated in the database;

- As a response to the EIRs, the BIM Execution Plans (BEPs) need to ensure that the supply chain processes will deliver Asset Requirements that can be retrieved and reused by non-design experts; and

- Following the BEPs, the PIMs will include data that can be used by the Asset management teams to inform their operational decisions after handover.

Technology support: to achieve the above processes it is important to ensure that technology supports and not hinders these capabilities. As a minimum requirement:

- Interoperability should be ensured across BIM tools (BIM authoring tools, Common Data environment) and Asset Management Systems, Software agnostic solutions such COBie, .csv and IFC files could be used;

- By recognising that data will be maintained in an electronic format throughout an asset's lifespan, there is a need to ensure data will have a unique ID so that it will get protected from being lost or overwritten; and

- Asset Management Systems have the functionalities to receive and capture data that can be used for lifecycle decisions.

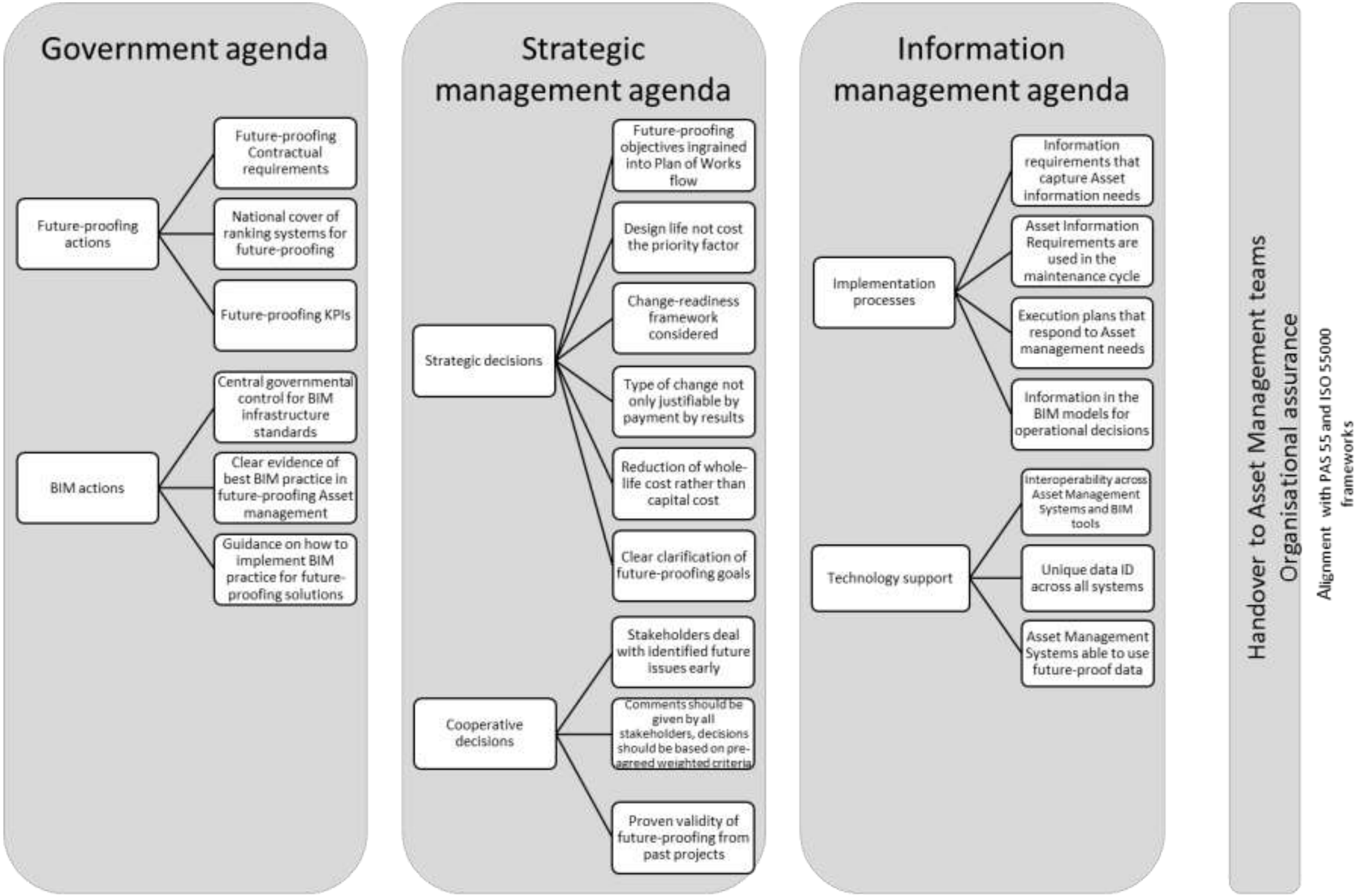

Figure 3: Future-proofing governance considerations / responsibilities per agenda.

Change-readiness framework

The following change-readiness framework provides clarifications regarding the range of 'what' could change as well as an indication of 'when' this could happen (Figure 4). Slaughter (2001) discussed three types of change that can occur within an asset regarding its:

Flow: the first type of change is looking at changes in:

- environmental flows – e.g. a change may be required to occur due to a climatic change or physical environmental conditions within the asset; and
- change in flow of people/things may occur from an organisational change decision.

Function: for infrastructure projects such changes may occur in:

- re-using existing functions – upgrading an existing space for better performance;
- creating new functions – creating an existing space for additional functions; or
- changing for different functions – altering the space for different functions to apply

Capacity: the third type of change is related to the structural transformation of the asset to meet specific performance requirements. Changes in capacity may occur from changes regarding the asset's 'volume' and/or 'loads'. Essentially, these changes are focusing on 'size'. Transformation is more rigid compared to the first two categories; these type of alterations are also more expensive

De Neufville et al. (2008) categorised three types of applications as they emerge into an asset lifecycle: Operational, Tactical and Strategic applications. The asset will perform as it was originally designed but in addition there can be an additional ability within the asset which can be described as a switch. In effect, the Owner can switch this ability on and off depending on the internal and external factors that emerge. Each type of application can be considered as moving from one level to the next whilst directing the asset to adapt to changing needs dynamically:

Operational or short-term applications are the lightest form of change and the easiest as it can be applied on a daily or weekly basis. This change finds application in light systems. The application can be cost effective whilst endorsing a rapid on-going change in the short-term;

Tactical or mid-term applications reflect more permanent response in the change scale and thus require significant capital to be reverted. In order for this application to be effective, the initial capital cost of the asset could be higher (10%-20%). The application is used to address medium-term uncertainty and to become effective it could take a few weeks of implementation; and

Strategic or long-term applications are strategies that Owner Operators could apply considering the end life of the asset. The effort of deploying this option is to significantly increase the life expectancy of the asset. Owners would expect this application to become effective after years of handover of the asset.

Moreover, cost is increasing from one application to the next. The change-readiness framework is used for informing an effective future-proofing approach. An exercise of identifying options across this graph reflecting the asset's lifespan can inform the 'lifespan asset optioneering' exercise in the mutation cycle as discussed later in the following section.

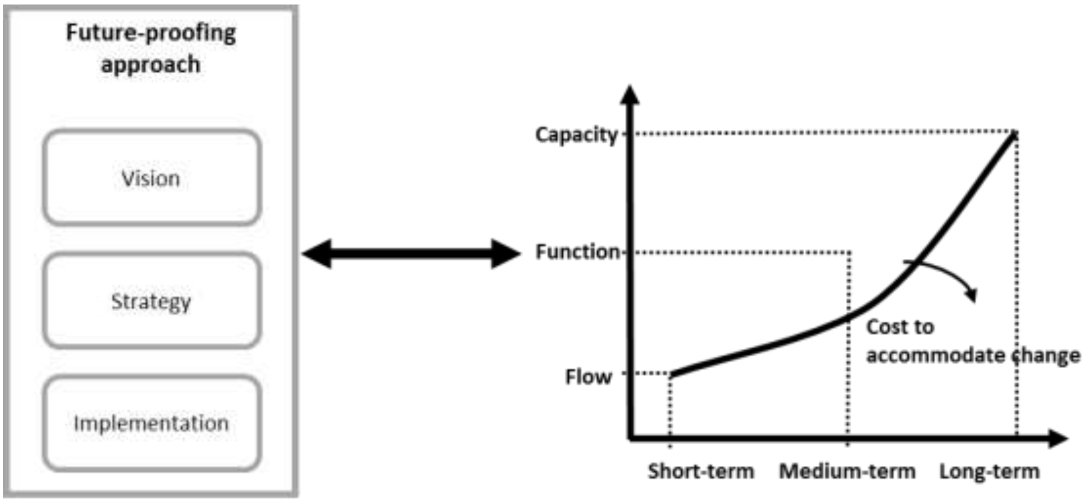

Figure 4: Change-readiness framework aligned with future-proofing approach.

BIM capabilities that support future-proofing

As discussed in the previous sections, there is real opportunity for both the Clients and the Supply partners to benefit from the use of BIM. This metacritique serves as identification of the qualitative competences that exist in a BIM process environment. The following supportive capabilities have emerged and are summarised in Figure 5:

Flexible data: flexibility in this instance means that the data can be used by multiple teams across the project and throughout the asset's lifespan for multiple purposes. To ensure data flexibility, there needs to be a standard procedure for information exchange and systems interoperability. All of these challenges are trying to be addressed within a BIM process.

Optioneering capabilities: Optioneering studies are becoming more easily implemented within a BIM process framework. Information has become easily accessible and this is further supported by technology advancements. BIM offers not only the possibility of running many 'what-if' scenarios to choose the best possible solution based on the Clients' requirements but it can also be used for evaluating possibilities regarding the scenarios an asset can accommodate post-handover (lifecycle asset optioneering).

Project evaluation: BIM is also becoming a quality assurance process for evaluating models and validating data input. In terms of FP, BIM can be used for quantifying how future-proof an asset can be, identify resilient-sensitive areas and inform decision making.

Standardised object catalogues: Just like the automotive industry, it is now possible to have libraries of components that can be re-used from project to project, saving time and resources. These components and their properties can in addition be backed up with evidence i.e. performance, durability, maintenance conditions etc. to better support future-proofing decisions.

Whole-life costing: essentially this is the main purpose of moving towards BIM process delivery. The PAS 1192-2 (BSI, 2013) and PAS1192-3 (BSI, 2014) specifications outline how a CAPEX model will be used to support OPEX purposes. With BIM it is now possible to have whole-life cost models in place and evaluate future scenarios about the asset in question. The design models can be linked to cost databases that effectively investigate the best solutions from a pool of solutions that are ingrained within the design model itself.

Whole-life communication: Communication of requirements, rich-based complex databases, early data that can be useful for the Asset management teams are only a few examples that make communication the strongest capability of BIM. Communication is the key for effective delivery of change-ready assets and volumetric design, software agnostic exchange packages (i.e. COBie) and visualisations are some of the examples of this capability.

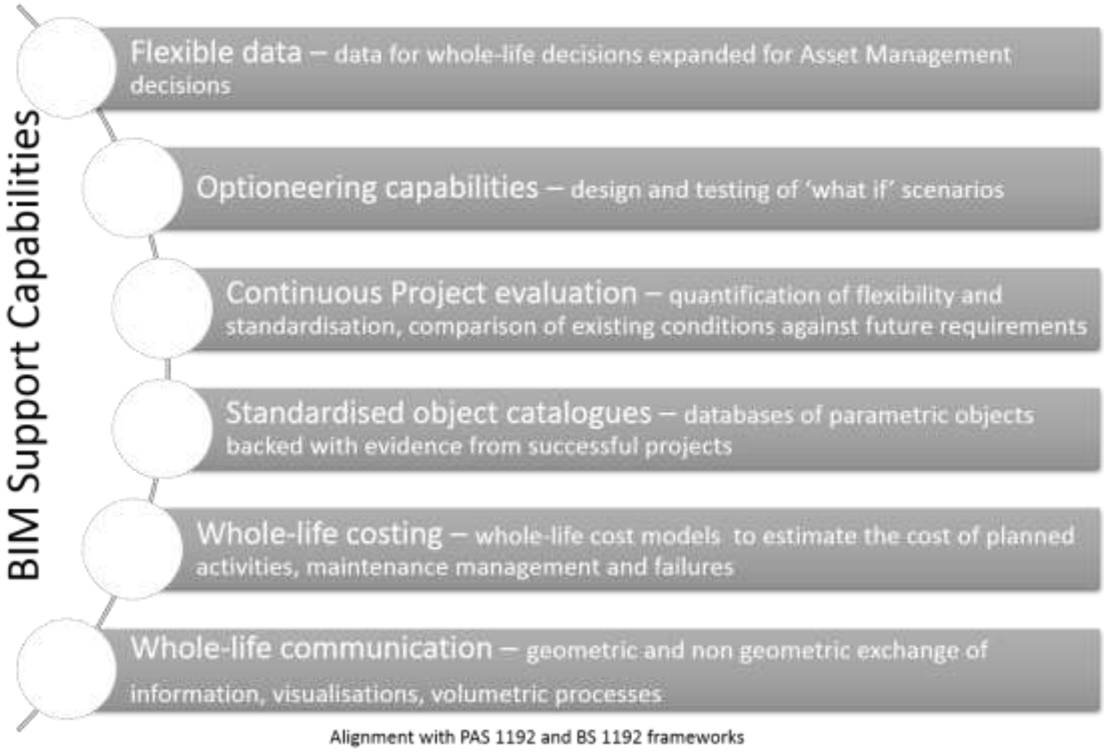

Figure 5: BIM support capabilities for future-proofing development.

Lifecycle asset optioneering and mutation asset lifecycle

The previous sections captured the governance considerations for lifecycle asset optioneering as well as the qualities offered from the adoption of BIM. In this section, a mechanism is proposed that takes into effect the above two. Present approaches involve the Client procuring for a new development suggesting that the supply teams need to provide a number of proposals (approximately three) and then, after evaluation of the three propositions the team will produce a feasibility study based on a Single preferred option (SPO). Future-proofing takes a different stance and suggests that the Clients should steer their approaches on a different direction. Considering the above it is then possible to re-engineer the procurement process and stimulate alternative design approaches that will protect the lifespan of the asset. Implying a switch is incorporated into the asset, it is then possible that during its lifespan the asset will be able to readjust itself into the business needs the organisation is required to respond. The asset lifespan in essence becomes the mutation cycle identified in Figure and instead of a SPO, the Clients acquire a Current preferred option (CPO) solution. A CPO identified in the initial stages ensures that the design will have the insurance embedded into the asset that will allow it to address change at a set period in time.

Post-handover the Asset lifespan initiates and the Asset will eventually be challenged by many internal (new policies, change of services etc.) and external factors (political, environmental etc.). This is when the 'mutation' cycle initiates and FP comes in effect. Unlike the present planning approaches and an SPO outcome, the mutation cycle is divided into mutation periods and each period has a CPO (top rows in the graph). The asset then remains *current* to the new set of factors that determine the asset's use at a particular span or *period* in time. Assuming the factors will change at some point in the future then the mutation period will come to an end and the asset will readjust itself. The Organisation will re-evaluate its business scope and identify from a pool of scenarios the most suitable CPO.

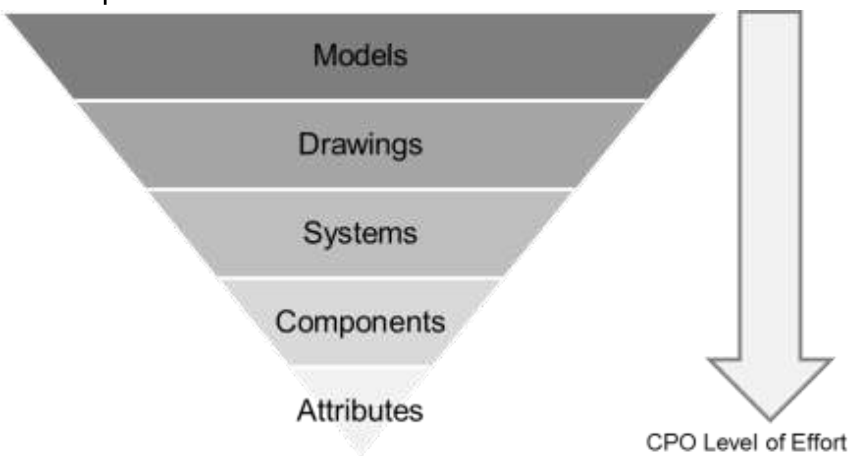

Figure 6: Current preferred option levels of effort.

The lifecycle asset optioneering activity materialises from the context of the change-readiness framework and the BIM capabilities (see previous section). The outcomes, i.e. the CPOs are stored into the asset's database, where the Clients and Asset management teams have access post-handover to inform their decisions. The CPOs consider a range of occurring changes during the asset's lifespan which are informed by the change-readiness framework (discussed earlier). In terms of data representation, these could be models, drawings, systems, components and attributes (Figure 6). The data will be stored in the BIM database and at a later point in time these will be available for retrieval and be used at any of the decision points shown in Figure 7.

The CPOs with the use of the employed BIM capabilities and through Asset management data capture processes will feed information back to the database, increasing the volume of data and also updating existing. It is outside of the scope of this study to describe in detail the process of retrieving and re-using information from databases to inform decisions, however extended research has been taken by other researchers (Demian 2004; Masood et al. 2013). Lastly, the mutation cycle cannot be implemented if the above process is not identified by the delivery teams and the Client during the early project stages of delivery.

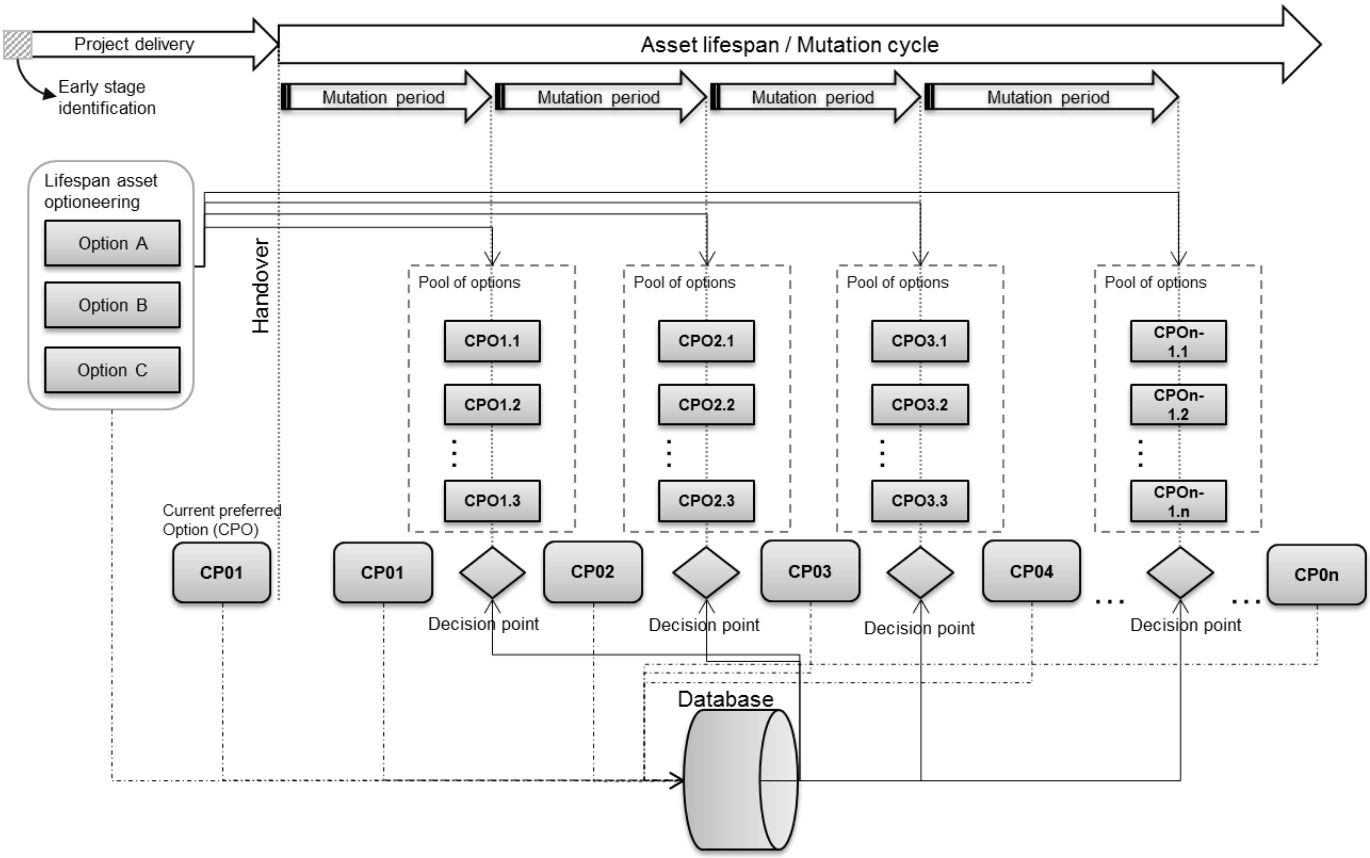

Figure 7: Lifecycle asset optioneering and mutation asset lifecycle

DISCUSSION

For efficient Asset Management, Clients and their supply partners should work together to establish an infrastructure of information delivery prior-handover stage. The assessments that were carried for the purposes of this study showed that Asset Management can be detached and not find support regarding the handover of data that is 'fit for purpose'. In this instance, 'fit for purpose' is data that is produced from inception to construction and can further be used for O&M purposes post-handover within a BIM environment. Asset management frameworks (Taggart, et al., 2014) can be effectively applied in infrastructure projects if there is a) provision of useful information and b) awareness that there is uncertainty hidden within the asset's lifespan.

Clients should push their suppliers for more holistic outcomes and target for whole-life cost reductions within their schemes. Indeed the Government mandate is that public projects should be delivered in BIM, but that does not warrant that the assets will still be fit for purpose 50 years after their completion. Nevertheless, FP should not only be about major expansions. Major savings can be accomplished by simply setting the right 'fit for purpose' data in place and in an accessible format. This will mean that other teams will be able to use and make informed decisions regarding the life of the asset. These informed decisions will originate from the data that comes with the delivered physical Asset.

Construction needs to drive towards a focus on whole-life cost reduction rather than capital cost reduction and findings from Mevellec and Perry (2006) and Wang (2011) among others note the importance of whole-life costing. Furthermore it was highlighted that standardised solutions need to have embedded agility in their uses so that they can be able to adapt. In addition, delivering projects that have the ability to deconstruct rather than being demolished is another important aspect of design and a great example of such design approaches can be seen in Kings Cross Station (King's Cross Central Limited Partnership, 2014).

The realisation that change is inevitable, should question whether mandatory changes will occur too late when future requirements demand it, - and thus having increased cost of changes - or ideally we will build a 'platform of awareness' in which change will occur as Hamel and Prahalad suggested, in a 'controllable environment' (Hamel & Prahalad, 1996). This platform eventually should include a future-proofing 'insurance' procedure and 'fit for purpose' data as deliverables of this process. As shown in Figure 8, the cost of design changes can be reduced in the MacLeamy curve if a BIM workflow is implemented early in the project and in addition the project is covered by a future-proof insurance. In order to protect the assets a series of governance measures and change in the optioneering process is suggested.

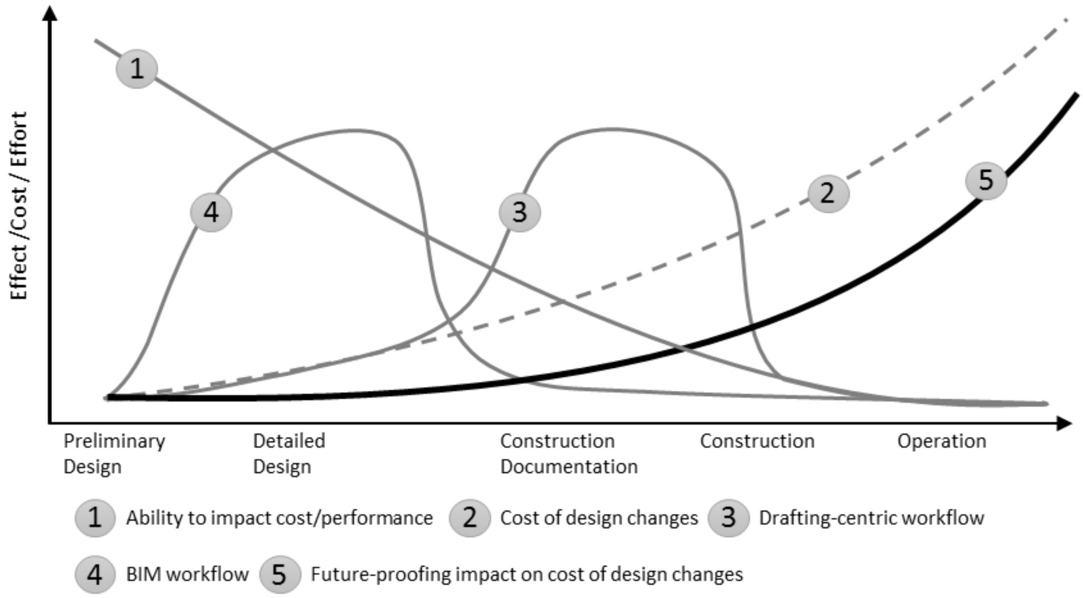

Figure 8: The MacLeamy curve and FP impact on cost of design changes.

Figure 9: Building blocks to support future-proof Asset management decisions.

CONCLUSIONS

To future-proof our assets and consequently the management of them, there is a need for establishment of a series of high-level protection measures against uncertainty. These measures have been outlined within three agendas, namely, Government, Strategic management and due to the opportunities that BIM brings, Information management. These agendas can only be implemented if they are supported by the BIM capabilities offered within the BIM process. Both, agendas and BIM capabilities should work as building blocks that support Asset Management. If the Asset management teams have access to such information they then have valuable support and it is then possible that decisions could be taken around future-proof lifecycle development. The decisions will be better supported with evidence and will be more informed, hence leading to better lifecycle decisions (Figure 9).

To achieve the above, the teams are working on a change-readiness framework to inform the lifecycle asset optioneering process. The outcomes of this optioneering activity are used to inform decisions taken throughout the mutation cycle. The mutation cycle is essentially the asset lifespan amplified with FP to withhold against uncertainty which essentially informs the Asset management teams make better decisions. As cost reductions in the construction and the sustainability agendas become more and more important, both the Clients and their supply partners aim throughout the lifecycle of the asset to facilitate assets that are able to respond to a mutation cycle.

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APPENDIX E

Using BIM to Integrate and Achieve Holistic Future-proofing Objectives in Healthcare Projects[17]

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Future proofing (FP) is an urgent need in healthcare buildings, due to unforeseeable demographic shifts and rapid advances in medical technology. Building Information Modelling (BIM) offers many opportunities, but evidence needs to be documented regarding the synergy between FP and BIM. The aim of this study is to investigate the perceptions of healthcare construction experts about the use of BIM for integrating holistic FP objectives for delivering healthcare construction projects. Interviews with 13 senior managers were conducted and analysed and an interaction matrix of BIM functions for implementing holistic FP objectives has been developed. The outcome is a taxonomy analysis of 30 interactions with supporting empirical evidence. For benefits realisation in the context of BIM and FP, the industry experts recognise FP as a strategy that supports Organisational and Building performance. In addition, BIM drives towards Lifecycle Operation Information and Data Maintainability via communicating the FP strategy from a whole-life perspective and ensuring knowledge transfer across all stages. Healthcare Operators and healthcare construction experts should be able to benefit from this taxonomy analysis as an aid to implementing BIM to support FP.

Keywords: Building Information Modelling, Organisational change, Project planning, Strategic management.

[17] Krystallis, I., Demian, P. and Price, A.D.F., 2015. Using BIM to integrate and achieve holistic future-proofing objectives in healthcare projects. Construction Management and Economics, 33(11-12), pp.890-906.

INTRODUCTION

Healthcare and its executive teams face a policy environment characterised by change on several fronts (e.g. reforms in health services, government initiatives for improving working conditions of staff etc.). With change there is uncertainty and thus has an impact on the ongoing delivery of service strategies, organisational culture and the way the Trusts (divisions within the UK's National Health Service, NHS) operate locally. According to Capper et al. (2012) the main issue is the reluctance of the NHS system to enforce strategies that will address sustainability related planning conditions.

Healthcare assets exist in a complex operational and technological environment and thus identifying the Requirements Information (from early concept stages) from a whole-life information management perspective is crucial for ensuring design life. Additionally, global austerity measures are causing reduction of investments in all sectors, and the construction sector is no exception. However, owners are seeking other ways to overcome the financial crisis by investing in the application of sustainability; and for a building to achieve sustainability the designers recognise that it has to be also future-proofed (Krygiel & Nies, 2008). While the traditional idea was to design and deliver healthcare facilities as "complete" projects, in other words projects with fixed requirements; it has transpired that hospitals are very complex dynamic facilities and cannot be built as programmatically static (Carthey et al. 2010; de Neufville et al. 2008; Kendall 2005; Thomson et al. 1998). In this context, Francis (2010) stressed the question "how can we ensure that what we are building now will be fit for the future?" and then proposed that a dynamic system approach is necessary to deal with change.

Masood et al. (2013) suggested that "information could also play an important role in supporting whole-life decision-making". In support of the above and following the USA and the Scandinavian countries as previous successful examples, the UK has set forth a BIM initiative which emerged from the 2011 construction strategy (Cabinet Office, 2011) and suggests that construction savings can be achieved if the construction industry manages better the information it produces. One of the key challenges from a planning point of view is whether information will be fit for purpose in the long-term. At the outset, a definition of the two concepts, BIM and future-proofing, needs to be drawn. The UK Department of Health (DH, 2013) recognised 13 issues that need to be addressed at each project stage of a healthcare project regarding excellence in sustainability; one of them being future-proofing. Masood et al (2013) defined future-proofing as “the process of incorporating future developments while changing from an unplanned and uncontrolled state to a planned and controlled state of a resilient infrastructure asset or product service system with minimal negative consequences”. For the DH (2013) future-proofing is a response where “buildings should respond to future changes in requirements, change of use, strategic perspectives, clinical/medical drivers, national policy and changing climate”. In the remainder of this paper, future-proofing is proposed as the dynamic system approach that can address change.

There have been many definitions of BIM and all of them describe a change in process in terms of construction management (Demian & Walters 2014; BSI 2014; BSI 2013; Ashworth 2012; Eastman, et al. 2011; Shade, et al. 2011; BSI 2007). For the purposes of this research, BIM can be defined as:

Building Information Modelling (as a verb) is the process of generating and managing component data within an integrated database and parametric model throughout the project’s Design-Build-Operate lifecycle.

The result is a Building Information Model and can be defined as:

A *Building Information Model* (as a noun) is a digital representation of all physical and functional characteristics of a facility or site serving as a shared knowledge resource for information about the assets. This knowledge database forms a reliable basis for information exchange and decisions during a project's lifecycle from inception onward.

The parallel adoption of these two concepts could bring confusion when clients and the supply chain assess their impacts and effectiveness. Does BIM have the capabilities to support a planning approach that prepares the asset against future changes in requirements? Which characteristics of BIM assist more and which could potentially hinder future-proofing flows? What are the synergies of future-proofing and BIM? What are the benefits of working towards these two concepts?

The aim of this study is to develop a classification ontology of the interactions between the two concepts, based on empirical evidence that emerged from interviews with 13 senior managers experienced in healthcare design, construction and operation and BIM. These interactions establish the theoretical relationships that exist between the two concepts through a framework that juxtaposes future-proofing objectives throughout the project lifecycle, and BIM capabilities related to a future-proof whole-life management. These interactions should also clarify how BIM can be implemented for maximum alignment to future-proofing.

To accomplish the aim we:

- Articulated future-proofing objectives using a holistic approach. An **objective** is defined as a set of tasks taking place to accommodate one high level goal at a particular project phase;
- Identified tasks that help implement future-proofing as part of project management. A **task** is defined as a particular action that is grouped with other tasks to complete a goal, thus an objective;
- Identified which BIM capabilities contribute to the implementation of future-proofing strategies. A **BIM capability** is a particular feature of BIM that is used by the supply chain to develop, deliver, test and make use of particular information relevant to future-proofing; and
- Investigated whether BIM does indeed benefit any aspects of future-proofing.

LITERATURE REVIEW

Holistic Future-proofing

In literature, the concept of future-proofing covers areas such as protecting the built environment against climate change (Jentsch, et al., 2008), future-proofing buildings against future higher temperatures (Coley, et al., 2012), and energy efficiency (Georgiadou, et al., 2012). In addition, national and local frameworks have emerged, with a focus on effectively managing public health risks to achieve climate resilience (HM Government, 2013).

As discussed above, future-proofing has often been presented as a process that deals with environmental and energy saving issues but healthcare organisations are dealing with change in many more additional aspects. Criticality plays a major role in healthcare; unlike other types of buildings, healthcare buildings cannot afford major redesigning because of the impact this will have in the clinical service provision. From a client point of view, there have a number of procurement methods that would specify healthcare project delivery and thus how future-proofing could be approached; all of them having advantages and disadvantages. Public-private partnerships (PPP) and Private Finance Initiatives (PFI) are commonly practiced in the UK for their long concession periods (Javed, et al., 2014). Fast-track procurement is often a preferred option because of the overlapping ability to undertake delivery tasks. However this comes with increased risks and costs (Bogus, et al., 2006). Integrated Project Delivery (IPD) is branded as a non-traditional method where the teams come together early utilising innovative technologies and thus collaboration is increased (Lahdenperä, 2012). As an alternative route, the client may choose the Design-Build type of contract but evidence has shown that these types of methods may bring confusion regarding the designer/contractor role (Larsen & Whyte, 2013). In order to increase building and operational performance, there is an increased number of clients which impose a Soft Landings framework in their tender documents where the supply chain is obliged to be involved after the handover of the project (Way & Bordass, 2007).

We have summarised a list of tasks found in literature (Table 1) and covers future-proofing with regards to the whole project phases. The objectives emerged from the literature analysis and in essence they serve to categorise/group tasks with similar scope and aim; they are described in detail later in this paper. Having a set of tasks from the literature, interviews where then used to identify additional tasks that will give us a more complete aspect of implementing future-proofing in healthcare projects.

'Insert Table 1a here'

'Insert Table 1b here'

'Insert Table 1c here'

BIM for Future-proofing the Healthcare Built Environment

Research on ecological landscapes suggested that institutional and organisational landscapes could be approached the same way, in order to contribute to the resilience of socio-ecological systems (Olsson, 2004). The features identified by the authors included: legislation that creates social space; funds availability for responding to environmental changes and for remedial actions; ability to respond and monitor environmental feedback; information flows and social networking; combination of various sources of information; sense-making of the collected information; and platforms of knowledge sharing.

Most of the above features can be applied in today's construction 'ecosystem' too and moreover, information workflows, collaborations and interacting communication platforms are achieved by embracing BIM principles. The Cabinet Office BIM Task Group stated that BIM is "a managed digital information 3D model of an asset, be it a building or an infrastructure project (both new-build or retained estate) that is infused with data. This information can be used to inform the decision-making process and answer questions throughout the entire project lifecycle. One BIM input can give us many valuable outputs" (NBS & RIBA Enterprices, 2012). BIM has the capability to affect the core processes and products of design and construction and affect all the professions evolved in throughout the project lifecycle (CIC 2013; Eastman, et al. 2011; AIA 2007). BIM also warrants an innovative approach at information flows and communication in design and later in construction (Demian & Walters, 2014). The MacLeamy curve highlights that the required time of design and construction delivery can be shortened significantly by to the adoption of BIM processes as opposed to traditional delivery methods. Also, adoption of BIM workflows and the impact of cost and performance are highly associated as both factors influence (can be influenced by) the early stages of the projects and are interconnected (Light, 2011). In early design phases, BIM can be used to facilitate various model based scenarios and influence decision-making (Shade, et al., 2011). One of the great impacts in construction is that everyone in the industry can not only share data but in addition this data is shared through a common platform (Ashworth, 2012).

For design, BIM signals a paradigm shift from drafting to modelling, which enables design decisions to be made with more foresight. BIM can be used as a central repository for building project information throughout the asset's lifecycle (Grilo & Jardim-Goncalves, 2010). However, in the designers' views, 3D models that are used in design do not have the maturity yet or the FM teams have not developed process that can use these models in relation to the benefits provided by the maintenance systems they already use (Korpela, et al., 2015).

In healthcare construction, an example where facility and clinical information are linked to support managing healthcare facilities was presented in Lucas et al. (2013). Innovative engagement processes as part of a BIM based solution were used to enhance decision-making in healthcare facility management (Irizarry et al., 2014), while a healthcare related problem scenario where BIM and healthcare specialist software ActivityDatabase are used concurrently on refurbishment projects was presented by Krystallis et al. (2013). It seems that healthcare is a sector where BIM can be exploited in many more innovative ways.

In summary, the two concepts are two independent initiatives in the UK (BIM is pushed by the BIM task group (http://www.bimtaskgroup.org/) whilst future-proofing is part of the sustainability agenda proposed by the Department of Health (DH, 2013). There seems to be a lack of systematic investigation of the interplay between the two concepts. It seems that additional evidence is required to explore whether the two concepts are dependent on one another and if they are, then to what extent. In the remainder of the paper an attempt is made to identify the interrelationships that exist between the two.

RESEARCH METHOD

Interpretative Phenomenological Analysis

The study adopted Interpretative Phenomenological Analysis (IPA) for recordings of perceptions. The aim of IPA "is to explore in detail how participants make sense of their personal and social world, and the main currency for an IPA study is the meanings particular experiences, events, states hold for participants" (Smith, 2010). Both IPA and Thematic Analysis (TA) could have been used for data analysis, but IPA was chosen due to the fact that future-proofing was studied as a phenomenon and the nature of the interview questions were closely related to that type of method. The theoretical lens used in analysing and interpreting the perspectives of the interviewees comes from the cognitive rather than the behaviourist paradigm that is broadly used in social sciences (Smith, 1996).

The 'first-order' stage analysis took place once all the transcripts were completed (Larkin, et al., 2006). A transcript was randomly picked and was read several times. First, initial themes were documented followed by emergent themes. The emergent themes were grouped together to provide 'grouped' themes, which in turn were reconstructed into High-level, Mid-level and Low-level themes according to the focus level they addressed (Larkin, et al., 2006). The same process was followed with the rest of the transcripts, and the grouped themes that emerged were aligned back to the first set of high-, mid- and low-level themes that arose from the previous transcripts and wherever that was not possible new themes were added.

The 'first order' stage summarises the participants' concerns and does not develop any further interpretative or conceptual level (Larkin, et al., 2006). That 'interpretation' was done in the 'second-order' stage, where the investigator provided a critical and conceptual commentary upon the sense-making perceptions of the participants (Smith & Osborn, 2008). In this second stage, engagement with existing theoretical constructs as well as interpretations about 'what it means' were used for the development of the framework (Table 6). More information about the conceptualisation of the framework can be found in Sacks, et al. (2010). At this stage, we quantified the items found under future-proofing implementation and mapped them against the identified BIM capabilities, both of which emerged from the IPA interpretative part.

IPA Analytic Process

Firstly, we conducted a literature search about future-proofing and selected sources which discuss it from a broad research spectrum. These were put together in task form and placed in a catalogue (pool of tasks). Then, we undertook interviews with healthcare experts and two themes emerged from the data, the first being future-proofing specific and the second for BIM capabilities related to future-proofing. The first theme offered a new set of tasks which in turn were added to the catalogue, together with the tasks derived from the literature. A summary table of the background of the interviewee healthcare experts is presented in Table 2. Table 1 outlines the tasks found in literature; the tasks identified by the interviewees are summarised in Table 3. The objectives shown in Table 1 come from Table 5 and were used to group tasks with similar scope.

Each task was assigned a label according to the project phase in which it is found (i.e. P-I is a task found in [P]lanning phase etc., and the Roman numerals indicate the sequence of the objective within a particular phase). The BIM capabilities that were found are presented in Table 4. A combination of both sources of tasks (literature and interview data) was used and the outcome was the development of the objectives (Table 5) where they were further aligned to project phases. We developed an interaction matrix (Table 6) after analysing the interrelationships in the cross tabulations of the objectives (Table 5) and the BIM capabilities (Table 4). The table summarises the interactions by counting each interaction as it occurs throughout the identified phases. All interactions emerged from the IPA analysis and later the results were quantified to 'weight' the interactions against the framework and thus giving a whole-life perspective of the two concepts.

This interaction matrix aims to underpin theoretical relationships that exist between the two concepts. An attempt was made to support the emerging interactions with empirical evidence coming from experts, as presented in Table 7 - Table 12. The inclusion of verbatim extracts in these tables "helps the reader to trace the analytic process, perhaps including more acknowledgment of analysts' preconceptions and beliefs and reflexivity might increase transparency and enhance the account's rhetorical power" (Brocki & Wearden, 2006).

Sample

Semi-structured interviews were conducted and the interviewees are both procurers (five Program and Owner Operators) and delivery side (eight consultants and major contractors). Furthermore these interviewees were selected for their specialist background in healthcare construction and understanding of BIM. Most of the interviewees had served in this area for more than 10 years and as such they had vast experience in different types of healthcare projects and procurement methods. Due to this, they were able to bring examples of good practice from various types of contracts, which would provide some reassurance of the generality of the results, irrespective of the type of contract used. In addition, the good balance between procurers and the delivery side reduced bias in the emergent themes towards the demand or supply side.

'Insert Table 2 here'

RESULTS AND DISCUSSION

Future-proofing aspirations

The views of the interviewees with regards to aspects of future-proofing have been summarised into eight categories (Table 3). Each category reflects one particular capacity of the concept. Below the eight aspirations are discussed in detail and in addition the tasks found from the interview sessions have been mapped against the eight aspirations in Table 3:

9. ***Setting of initial future-proofing targets*****:** The interviewees suggested that the setting of initial targets should be around establishing the principles for future-proofing in their design strategy. Those principles consider various aspects e.g. investigation of future services, clients' information requirements regarding considerations, standardisation agenda etc.

10. ***Investment options:*** Future-proofing considerations can be used for Portfolio and Asset management. The interviewees highlighted awareness around business opportunities that may rise in the future of an operating healthcare asset and how these may reflect in the asset. The opportunities consider future collaborations with nearby private providers and distribution of services accordingly, provision of unused spaces for patient welfare etc.

11. ***Adaptive to future-proofing needs procurement method:*** Contractual agreements seem to hinder aspects of the concept and the interviewees highlighted particular parts of current methods they believed will enhance it.

Among others, Fast-track was mentioned as a method suitable for addressing uncertainty (although it was recognised that adoption may increase costs by 20%), which is also highlighted in (Bogus, et al., 2006); the Private Finance Initiative (PFI) as an example of extending the brief and Integrating Project Delivery (IPD) for involving the FM as early as possible.

12. ***Necessary building flexibility:*** An integral part future-proofing is having flexibility incorporated in the design. Speaking from experience the interviewees filtered the most useful concepts of flexibility that are usually used when delivering healthcare facilities. Sacrificial systems (i.e. walls with no M&E systems input) and soft spaces (i.e. offices), concrete frames and open spaces have been mentioned among others.

13. ***Healthcare-specific design scenario factors:*** The interviewees identified the tasks they perform when looking at 'what-if' scenarios during the design process. Aspects such as activity projections, patients flow, room adjacencies etc. are some of what was identified by the interviewees to develop their business case.

14. ***Repeatable standardised spaces:*** Although at first sight standardisation may seem to contradict flexibility, there are particular features that make standardisation attractive for delivering future-proof solutions. For example, employing limited general NHS rooms was found to allow an existing space to be used for other uses. Repeatable spaces which improve service delivery (i.e. increase familiarity to staff coming from other hospitals) were mentioned too.

15. ***'What-if' data for maintenance solutions:*** The data provided early in the project will be used to better support the FM decisions at the operational stage. Data such as maintenance equipment factors, projections of future use and how

these will affect service maintenance could be incorporated into information exchange packages which may be used at later stages.

16. ***Adaptive management:*** Lastly the interviewees identified the importance of adaptive management for future-proof solutions. For example they suggested that lessons learnt from other sectors (e.g. oil and gas, and the automotive industry) where the production environment is always adaptable to new products (i.e. development of new cars while the workflow of existing cars continues) should be used as example to improve processes in the healthcare sector.

'Insert Table 3 here'

BIM capabilities related to future-proofing

This section summarises capabilities that relate to future-proofing as identified by the healthcare experts (Table 4). The capabilities are grouped into six categories and reflect the specific areas where BIM is used for implementing future-proofing. Additional BIM capabilities exist and have been documented in the literature (e.g. Eastman, et al. 2011; Sacks, et al. 2010), but not all of these necessarily add value to future-proofing in the experts' opinion. Identifiers have been added in Table 4 which refer to subsequent tables for further description of how the six categories found here are used for future-proofing and BIM.

'Insert Table 4 here'

Holistic future-proofing objectives

After interviewing the healthcare construction experts, the tasks presented in Table 3 emerged and were later compared against the tasks found in the literature (Table 1). These two sources of tasks were combined to draw out the following objectives (Table 5). At the top of the hierarchy, the objectives represent the overall scope of each category and are decomposed into tasks for each specific setting. These tasks focus solely on implementing future-proofing strategies and are intended to be used alongside standard procedures (e.g. CIC Scope of Services) when delivering a project. Compared to the aspirations presented in the previous section (Table 3), the objectives provide guidance on what deliverable is required at a particular phase. Future-proofing delivery is gradually developed at all phases which means that objectives found in each phase replace those from the phase before.

'Insert Table 5 here'

Generation and Interpretation of the BIM- future-proofing Interaction matrix

The framework is reviewed to test the support of the identified BIM capabilities (Table 4) to the holistic objectives (Table 5), as shown in Table 6. The matrix can be interpreted in many ways and valuable conclusions can be extracted regarding the synergy between the two concepts. Some of the interactions reflect project management interests, some design and construction issues and some reflect operation interests. The index numbers in the cells of Table 6 express an understanding of the BIM uses to implement future-proofing; the numbers are explained in the key tables, Table 7 – Table 12.

The cells are shadowed and reflect the level of association between a BIM capability and an objective and thus when a cell appears in a darker colour it means that the objective highly benefits from that BIM capability (many interactions support the objective); for light shaded cells there is less to no association (see label in Table 6). In addition, Table 7 - Table 12 use evidence from practice to support the identified interactions that emerged.

The objectives with the most interactions were found to be *P-IV: Identification of flexibility* (18) while *P-I: future-proofing brief setting* and *D-III: Demonstration of flexibility plans* shared 17 interactions each. In addition the implementation of D-III objective was found to be highly related to multiple BIM capabilities (4), while P-I and P-IV were found to be highly associated to (3) BIM capabilities each.

The BIM capabilities with the most interactions across a project's life-cycle were found to be *Whole-life communication* (64), *Flexible data* (40) and *Standardised space catalogues* (39). More specifically, *Whole-life communication* and *Flexible data* were found to have interactions in all objectives but one. The interactions that appear the most are *Adaptable data for various actors* (15), *Benchmarks and recommendations* (14) and *Reducing the cost of resources* with 13 interactions.

The objectives with the least number of interactions were *P-III: Adaptive-friendly procurement method* (0), followed by *CO-II: future-proofing of working conditions* (3), and *Responsiveness of government strategic goals* (6); the healthcare experts could not associate those objectives with any of the identified BIM capabilities. There could be several reasons for this: the experts do not find it useful to use BIM for such objectives, or they are not aware of how to use for these objectives. The weakest BIM capability was found to be *Whole-life costing* (26) when compared to the other capability categories.

Bynum et al. (2012) found that BIM has a stronger application in project coordination and visualisation than it has for sustainability. Others found that the representations offered by BIM do not necessarily make the exploration of design solution space more effective or efficient, and that AEC professionals find solutions through what some authors referred to as ‘messy talk’ (Dossick and Neff, 2011). BIM was found not to foster collaboration across different companies, in contrast to increasing the collaboration among project members (Dossick and Neff, 2010). Non-technical organisational maturity was found to be more important than technological maturity in companies interested in adopting BIM. Researchers suggested that non-technical readiness should be addressed before technological readiness (Won, et al., 2013).

Interoperability issues are recognised and have been documented in a number of studies. Manning and Messner (2008) looked at healthcare case studies and found data transfer bottlenecks and a later study found that the industry had not yet found a way to resolve interoperability issues (Bynum, et al., 2012). Return on investment (ROI) issues have been discussed widely in literature, and Giel (2009) found that ROI is greater as the complexity of the project increases, thus making it more difficult to justify the need for BIM for smaller scale projects.

‘Insert table 6 here’

‘Insert Table 7 here’

‘Insert Table 8 here’

‘Insert Table 9 here’

References

'Insert Table 10 here'

'Insert Table 11 here'

'Insert Table 12 here'

CONCLUSIONS

In literature the two concepts are presented as two different initiatives and are not interconnected although they both seem to be focusing on change. Based on this, a classification ontology was created for assessing the interactions of the two concepts in question as they emerge in the healthcare built environment. The findings are two-fold: a holistic approach to the concept of future-proofing is provided. A list of objectives and tasks provide a thorough approach to future-proofing as a delivery concept as opposed to being solely a design (DH, 2013; NHS Confederation, 2005), sustainability (Krygiel & Nies, 2008; Georgiadou, et al., 2012) or investment solution (World Bank, 2010). In addition, a metacritique analysis of BIM was presented and the strengths and weakness of this process as it is reflected in the implementation of future-proofing is presented.

The 30 interactions were found to be repeated 237 times across Table 6. In terms of how a future-proofing strategy is progressing across the project stages the findings suggest it is at the early design stages where the preparation against uncertainty occurs regarding the asset life.

'Insert Figure 1 here'

For benefits realisation in the context of the two concepts, after distilling the 30 interactions it can be concluded that whole-life communication is the most relevant capability of BIM for implementing future-proofing and thus the objectives can be clearly communicated within the project's lifespan. The interviewees could better associate the objectives to organisational and building performance through BIM. In addition, BIM supports the development of lifecycle operation information via becoming a communication platform and thus ensuring 'data maintainability'.

Future-proofing and 'traditional' project data are being produced at a similar pace and during the operation stage additional operation data are being captured which results in information that supports and updates / maintains the adopted future-proofing strategy. In contrast, BIM for whole-life costing has not yet matured and more investigation is required. The above are summarised in Figure 1.

The 30 interactions documented in Table 6 and Table 7 - Table 12, present evidence from practice and demonstrate the strong synergy between the two concepts in healthcare construction projects. One limitation is that for projects with less complexity, BIM might in fact cause more challenges than benefits.

BIM processes drive rather than enhance future-proofing implementation and that derives from an ‘all-inclusive’ observation of the emerged interactions. BIM is used as the vehicle for delivering objectives at all phases and many of the interactions are repeated - carried over - from one phase to the next. BIM itself is not a concept with clear start and end times in project management; it is a multifaceted ongoing process where its capabilities are used to support and improve many concepts found in the built environment.

In addition, the taxonomy is supported with empirical evidence which showcases in detail the practical issues faced in projects implemented in BIM and future-proofing. Much like the equivalent interconnections between BIM and lean (Sacks, et al., 2010) the findings imply that delivery teams and clients working on encompassing future-proofing in their delivery strategy should ensure that their processes are adapted to meet the BIM principles.

On the other hand, the high number of interactions may suggest that a step change is required to include future-proofing in a BIM project and converserly any project that is targeting future-proofing implementation may face a step change to adopt BIM processes. Due to the high interaction across all stages it may be challenging to adopt one concept at early stages and then introduce the other at a later stage.

Considering that both two concepts are relatively new concepts in healthcare, more research and industry evidence is needed to foster the adoption of those two. The interaction matrix can be used as a framework for future research which stems from the identified synergies.

The study was only limited to interviewing healthcare construction experts and thus for linear projects the findings could be somewhat different. However, the objectives can be applied with minor modifications to sectors beyond healthcare (i.e. healthcare scenario factors may be replaced with relevant scenario factors found in the oil and gas industry etc.). Nevertheless it can be said that projects with great complexity, criticality and uncertainty can be highly benefited.

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Table 1a: Selected literature of future-proofing tasks aligned to project phases and emerged bjectives

Objectives	Tasks	Label	Source
Planning			
P-I: Future-proofing brief setting	Proposals addressing future services, and planning requirements	P1	(DH, 2013)
	Design brief includes plans for future change. Local planning objectives are taken into account	P2	(DH, 2013)
	Integration across hospital, community, primary, home	P3	(NHS Confederation, 2005)
	Reordering services in coherent processes	P4	(NHS Confederation, 2005)
	Financial, environmental, socio-economic considerations	P5	(Georgiadou, et al., 2012)
P-II: Investment options	Redevelopment strategy to provide for future expansion	P6	(VHA, 2012)
	'No-regrets' options – investment and policy options that provide benefits even when no change occurs	P7	(World Bank, 2010)
	Higher 'safety margins' for change and uncertainty in socioeconomic development	P8	(World Bank, 2010)
	Potential developments across the area. Connections with transport, commercial activities etc.	P9	(de Neufville & Scholtes, 2011)
	Consideration of future developments based on future site alterations	P10	(de Neufville & Scholtes, 2011)
P-IV: Identification of flexibility	Broad descriptions of adaptability and flexibility (future end user behaviour, future changes of building layout, technology lock in, upgrades etc.)	P11	(Pati, et al., 2008) & (Graham, 2005)
	Demonstration of future-proofing on parts with different uses (core, movable, essential)	P12	(de Neufville, et al., 2008) & (Slaughter, 2001)
	Assess infrastructure regarding future developments	P13	(NHS Confederation, 2005)
	Planning of shell space design	P14	(Kendall, 2007)
	Flexible design to accommodate new equipment, technology, changing service models	P15	(VHA, 2012) & (de Neufville & Scholtes, 2011)
	Distinction of likely expandable spaces-not expandable to areas where expansion is allowed	P16	(VHA, 2012) & (Krystallis, et al., 2012)
	Reversible and flexible options in case suggested concerns are wrong –insurance provision	P17	(World Bank, 2010)
	Weather-proofing Passive design strategies (e.g. high levels internal thermal mass, inclusion of solar heat gain, airtight construction, controlled ventilation, high levels of insulation)	P18	(Gething, 2010)

P-V: Responsiveness of government strategic goals	Awareness of government strategic framework	P19	(DH, 2013)
	Outperforming statutory minima (go beyond requirements of building regulations)	P20	(Georgiadou, et al., 2012)
	Policy making for adaptation needs to be adaptive itself	P21	(World Bank, 2010)
	Preparedness for climate change (overheating, flood issues etc.)	P22	(Jentsch, et al., 2008)
P-VI: Healthcare scenario factors	Best location of services based on patient pathways and models of care	P23	(Pati et al., 2008)
	Scenario analysis for long-term planning and assessment of strategies under a range of possible futures	P24	(World Bank, 2010) & (Georgiadou, et al., 2012)
P-VIII: Use of resources	Best use of people and infrastructure	P25	(NHS Confederation, 2005)
	Development control plan which tracks changes in service delivery	P26	(NHS Confederation, 2005)
P-IX: Whole-life assessment	Preventive maintenance plans	P27	(DH, 2013)
	Whole-life costing	P28	(Graham, 2005) & (Georgiadou, et al., 2012)
P-X: Knowledge systems	Participatory design through scientific and local knowledge	P29	(World Bank, 2010)
P-XI: Healing environment	Parklands, light, art, animals, social environments	P30	(VHA, 2012)
	Reduced ambient noise	P31	(VHA, 2012)
	Evidence based principles applied for well being	P32	(VHA, 2012) & (Price & Lu, 2013)
	Integrated information technology	P33	(VHA, 2012)
	Healing environment alongside reduction of resource consumption	P34	(VHA, 2012)
	Shared recreation and dining spaces	P35	(VHA, 2012)

Table 1b: Selected literature of future-proofing tasks aligned to project phases and emerged future-proofing objectives (continued)

Objectives *(continued)*	**Tasks**	**Label**	**Source**
Design			
D-I: Demonstrating change-readiness of design	Circulation and service infrastructure suitable to accommodate change	D1	(DH, 2013)
	Buildings able to respond to climate change	D2	(Coley et al., 2012)
	Open-ended routes for future expansion	D3	(NHS Confederation, 2005)
	Main circulation routes to remain steadfast throughout lifespan	D4	(NHS Confederation, 2005)

	Shallow plan spaces	D5	(Kendall, 2007)
	Building systems having the ability to expand/contract	D6	(VHA, 2012) & (Brand, 1995)
	Soft spaces used as sacrificial in between hard spaces	D7	(NHS Confederation, 2005)
D-II: Demonstration of maintenance plans	Guidance on performing maintenance tasks	D8	(DH, 2013)
D-III: Demonstration of flexibility plans	Graphic demonstration of suggested flexibility and preparedness	D9	(DH, 2013)
	Demonstration of future-proofing on different parts with different lifespans of the building	D10	(de Neufville, et al., 2008)
D-IV: Generic spaces & elements	Use of generic spaces rather than bespoke	D11	(Price & Lu, 2013)
	Built-in agility	D12	(NHS Confederation, 2005)
	Provision of generic rooms for range of health professionals to work	D13	(VHA, 2012)
	Long-term standard based structural frames and foundations	D14	(Gething, 2010)
	Group functions with similar requirements (multi-use)	D15	(Krystallis, et al., 2013)
D-V: Demonstration of disruption plans	Specification requirements for different zones of the building	D16	(Brand, 1995) & (Kendall, 2007)
	Ensure min. disruption of services for future upgrading	D17	(Georgiadou, et al., 2012)
	Design for deconstruction	D18	(Brand, 1995) & (Graham, 2005)
	Potential change of construction and fixing detail on site	D19	(Gething, 2010)

Table 1c: Selected literature of future-proofing tasks aligned to project phases and emerged future-proofing objectives (continued)

Objectives *(continued)*	**Tasks**	**Label**	**Source**
Construction			
C-I: Publication and application of future-proofing strategy on site	Strategy published to contractors to avoid unprepared alterations	C1	(DH, 2013)
	Necessary changes on site do not intersect with strategy	C2	(DH, 2013)
C-II:- Future-proofing working conditions	Working conditions-site accommodation	C3	(Gething, 2010)
	Temperature limitations for building processes	C4	(Gething, 2010)
Operation			
O-I: Awareness of future-proofing	Provision of as-built drawings to end users by the design team	O1	(DH, 2013)

strategy	Estates managers are aware of strategy	O2	(DH, 2013)
O-II: Feedback from future-proof project	Buildings are assessed on regular basis for flexibility and adaptability. Findings are used for future developments	O3	(DH, 2013)
	In case of demolition, evaluation of strategy - lessons learnt	O4	(World Bank, 2010)
O-III:- Reuse of components and materials	Future-proofing strategy ensures reuse of materials	O5	(DH, 2013) & (Georgiadou, et al., 2012)

Table 2: Classification of interviewees

Code Name	Occupation	Healthcare Experience (years)	BIM Experience (years)	Delivery side	Duration (min)
I-1	Director of design	11-15	0-5	Delivery	79
I-2	Health Director	11-15	0-5	Procurement	63
I-3	BIM Manager	11-15	over 16	Delivery	47
I-4	Health Director	over 16	0-5	Delivery	63
I-5	BIM Manager	11-15	over 16	Delivery	63
I-6	Director of design	over 16	0-5	Delivery	44
I-7	General Manager IT	6-10	0-5	Procurement	78
I-8	Health Director	over 16	0-5	Delivery	65
I-9	Director of design	6-10	11-15	Delivery	53
I-10	Facilities Manager	0-5	6-10	Procurement	43
I-11	Clinical Program Manager	over 16	none	Procurement	61
I-12	Senior Project Manager	6-10	none	Procurement	64
I-13	Director of design	over 16	0-5	Delivery	58

Table 3: Future-proofing aspirations in healthcare projects

future-proofing Aspirations	**future-proofing** tasks	Label
Setting of initial future-proofing targets	Investigation of future services (home based treatment, remote care, themed treatment etc.)	K1
	Client awareness for future-proofing requirements, earlier in discussion	K2
	Earlier consideration of the asset operation	K3
	Standardisation initiative	K4
	Regional requirements consideration	K5
Investment options	Collaborations with private healthcare and revenue for the NHS	K6
	Provision of commercial spaces for patient welfare	K7
	Identify where investment now will save money later (whole-life	K8

	costing earlier in discussion)	
	Towards corporate identity	K9
Adaptive to future-proofing needs procurement method	Fast-track mentality-build for uncertainty (i.e. big floor plates, ducts on regular basis) to address uncertainty at design freeze.	K10
	Brief extended to project's lifespan (PFI)	K11
	Documented opinion of maintenance providers (IPD)	K12
	Evaluation of design and construction decisions and materials selection	K13
Necessary building flexibility	Finding commonalities	K14
	Filtering spaces that can be changed/cannot be changed	K15
	Increasing clinical space/decreasing non clinical	K16
	Sacrificial systems	K17
	Finding differences among projects	K18
	Concrete frame more flexible than steel frame	K19
	Exterior prepared for expansion	K20
	Flexibility dependable on cost and complexity of the room	K21
	Long- mid- short- term elements of flexibility	K22
	Open spaces	K23
	Soft spaces	K24
Healthcare-specific design scenario factors	Activity projections	K25
	Commissioning of services	K26
	Future services, future treatments	K27
	Patients flow	K28
	Room adjacencies	K29
	Room usage data	K30
Repeatable standardised spaces	Employing limited universal repeatable spaces	K31
	Multi use (agile spaces) for whole life cost reduction	K32
	Repeatable spaces to improve service delivery	K33
	Standard specs for construction elements	K34
'What-if' data for maintenance solutions	Conditional levels of equipment linked to criticality	K35
	Criticality of equipment and services	K36
	Projections of future use for maintenance decisions	K37
	Maintenance equipment factors	K38
	Data relevant to maintenance teams (e.g. what type of change, how to deal, when to deal, how to do it etc.)	K39
Adaptive management	Adaptation of processes from other sectors	K40
	Representations of how future-proofing is linked to clinical efficiency	K41
	Sophisticated health trends data	K42
	Whole-life decisions at every stage	K43
	Use of evidence for estimation of changes	K44
	Minimum disruption of services	K45
	Estates managers are aware of future-proofing strategy	K46

Table 4: BIM Capabilities related to future-proofing as discussed by the healthcare experts

Ref table	BIM Capabilities for future-proofing
7	Flexible data
8	Optioneering capabilities
9	Project evaluation
10	Standardised space catalogues
11	Whole-life communication
12	Whole-life costing

Table 5: List of Future-proofing objectives and tasks assigned to them

Phase and future-proofing objectives	Labels	
Planning	**Literature (label column of Table 1)**	**Interviews (label column of Table 3)**
P-I: Future-proofing brief setting	P1-P6	K1-K3, K5
P-II: Investment and portfolio agenda	P7-P10	K6-K9
P-III: Adaptive-friendly procurement method	–	K10-K13
P-IV: Identification of flexibility	P11-P18	K14-K16, K18, K20
P-V: Responsiveness of government strategic goals	P19-P22	–
P-VI: Healthcare scenario factors	P23-P24	K25-K30
P-VII: Standardisation agenda	–	K31, K33
P-VIII: Use of resources	P25-P26	–
P-IX: Whole-life assessment	P27-P28	K21, K32, K40, K43
P-X: Knowledge systems	P29	K35, K36, K38, K42
P-XI: Healing environment	P30-P35	K45
Design		
D-I: Demonstrating change-readiness of design	D1-D7	K22, K23, K24
D-II: Demonstration of maintenance plans	D8	K39
D-III: Demonstration of flexibility plans	D9-D10	K19, K41
D-IV: Generic spaces & elements	D12-D15	K34
D-V: Demonstration of disruption plans	D16-D19	K17
Construction		
C-I: Publication and application of Future-proofing strategy on site	C1-C2	–
C-II:- Future-proofing of working conditions	C3-C4	–
Operation		
O-I: Awareness of Future-proofing strategy	O1-O2	K46
O-II: Feedback for future-proof project	O3-O4	K37
O-III: Reuse of components and materials	O5	K44

Table 6: Interaction table between future-proofing objectives and BIM capabilities

BIM capabilities	Future-proofing objectives: Planning											Design					Construction		Operation		
	P-I	P-II	P-III	P-IV	P-V	P-VI	P-VII	P-VIII	P-IX	P-X	P-XI	D-I	D-II	D-III	D-IV	D-V	CO-I	CO-II	O-I	O-II	O-III
Flexible data	1-4	2		2-4	3	2,3,5	5	3	1,4	2,3	3	3	2-4	3	5	2,3	1-3	2,3	1-4	1,4	3,4
Optioneering capabilities	6-9	7,8		6-9		6-9	9	8	7,9	8	7,8	6-9		6-9	9	7	7			8	8
Project evaluation	10-12	11,12		10-12	10, 11	10-12	10	10,11	10-12	11	10	10,12	10	10-12		11	10		12	10-12	10
Standardised space catalogues	19	17		13			13-19	14-16	15,17, 19	14,16	14, 16,18		14-17 ,19	16	13,15, 17-19	15,19	17		14-16		19
Whole-life communication	21,22, 24,26	20,26		22-26	20, 24	22, 24-26	21,22, 24,25	20,26	20,22	21,22	24,26	22-27	21, 23-25	22-25 ,27	22,23, 25,26	20,21, 23,24, 27	20,23, 24,26, 27	27	20-22, 26	20	25
Whole-life costing	30	29		28-30	30		30	30	28-30	30		28	30	28-30	28,30	28-30	28			29,30	30

Label: no association | low | moderate | high

Table 7: Flexible data - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
1	Gradual data - Data production aligned to each phase	"At the end of Stage 5 in construction you want the COBie data to include … a serial number of every single light in that four bed bay. You do not need that at Stage 2 though. At Stage 2, COBie is there to tell you that there will be a light which gives around 1000 lumens."
2	Expanded use of BIM to non-design tasks	"The ability to give the data of what real life is. E.g. a light bulb with all the real specifications; if I need to get a replacement I want to be able to print a shopping list and just go a get a buy it."
3	Adaptable data for various actors	"The data that a model carries can be used for a whole range of different subjects. From logistics, safety walkthroughs, visualizations, material take off etc. but it is not a different set of data."
4	Maintained data availability	"The key from my point of view is ensuring the information will exist in an existing facility in a form that can be reused 3, 5, 10 years down the track."
5	Online live databases linked to the model	"The idea is to build a BIM library of standard components and therefore you do not need to design the bedroom. What we actually did is having three standard bedrooms. All P21+ are going to be using just three models."

Table 8: Optioneering capabilities - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
6	Collaborative 'what if' scenarios	"BIM is a process which allows all actors to work on various scenarios on the same model. All the components put in by the different disciplines can be seen and tested within the virtual model."
7	Design integrity	"Inevitably it does not matter how much you do in 2D if somebody will forget that that column is actually there, whereas in BIM you cannot simply forget that."
8	Multi-purpose scenarios	"I think there is the case of having the design package on one end, and the software packages that look at flows and occupancy levels on the other end and then joining them together."
9	Quicker check of design alternatives	"Now it is much quicker [the design process] and because it is quicker we can manage our risk better because … we are looking at those optioneering possibilities and because we are able to put all those influences and drivers into the equation."

Table 9: Project evaluation - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
10	Benchmarks and recommendations	"You can't do any other way that it is quicker than the confidence of using BIM and you can find where the sensitivities are in the design."
11	Comparison of existing condition against future requirements	"I would want to know the 3D size of the space, what is in the space and how it worked. Patient flows that have been assumed. If I've got that information in place, when I then in the future start to reconsider those variables I can then successfully remodel what I currently have against my new requirements."
12	Quantification of future-proofing	"But because you could develop a BIM model and then use it to demonstrate at the early stage of the design process the end use of the facility and be able to say that not only have we thought about future-proofing, we can actually quantify future-proofing."

Table 10: Standardised space catalogues- Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
13	Have something to work with – not starting from scratch	"When you create a BIM model you are constructing it in a sense you can do it more quickly and more efficiently if you are dragging big component parts out of a catalogue rather than starting from scratch."
14	Increases familiarity of staff with workspace	"When staff is moving from one hospital to another there are actually no unfamiliar spaces so they can do their work more efficiently. So we are able to say how design is not mirrored it is repeated, i.e. the bed is always on the left for example and the clinical zone is always on the patients right hand side."
15	Minimises the need for disruptive stakeholder engagement	"It will reduce the amount of stakeholder engagement that is required therefore you do not have to take the clinicians away from their day jobs to be designing bedrooms again. These will be available as BIM data drops to be used."
16	Reduction of clinical errors	"There are also benefits to staff because those that have familiarity of the room and know where equipment is placed… so you have links to reduce clinical errors, when you have all these sort of design features being repeated."
17	Supply chain cost reduction	"And when use those [same] spaces in BIM you could then share that BIM information with the suppliers and the suppliers would hold that information which would cut their cost as well."
18	Repeatable design is linked to evidence and experience	"An anecdote were consultant X always knows what he wants e.g. six single beds etc. because that is how he has done for the past 20 years …but there are no actual evidence what he wants is going to help the patient so what we have done is to try and take the subjectivity away."
19	Specifications become default and	"Regarding future-proofing at least if we get our components right we can clarify our standard specifications, we can cut a list of element together … into the BIM model almost automatically, on the drawings, it will be on the

	automated input	business spec etc.”

Table 11: Whole-life communication - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice
20	Virtual representation and roadmap of future-proofing	“[BIM] is the most efficient way of achieving FUTURE-PROOFING and also the most efficient way of communicating that to the stakeholders because you can actually show them the 3D spaces and you can actually have a road map for what you got there. And it can all be edited in space.”
21	Operational knowledge	“I am immediately thinking of operational knowledge because e.g. we operate a hospital as of today and there will be 40 people running that project, they will all have a massive amount of knowledge about what works well in that hospital… if we could link that feedback from people actually using the hospital back to BIM databases.”
22	Communication of working specifications	“I would like to know about adjacencies. In a healthcare environment I think it would be information from the healthcare professional and where they think and how a hospital is going to work in the future.”
23	Fully multidisciplinary integrated model	“This is all about looking at a full integrated model, bringing the right aspects e.g. fire engineering, so that you have got a model that reflects good fire engineering practice; that shows how the services function, it shows you patient flows, visitor flows etc.”
24	Non-physical presence for design reviews and workshops	“The days of actually having a great big workshop in a great big room and inviting lots of people that is probably going to be unnecessary and things are going to be more virtually between teams.”
25	Standardised information process flows	“With BIM you can build an international team, e.g. with the airbus various components are built by various teams in various countries and it is all transported to France where it is being assembled. The process is accomplished by a multinational team.”
26	Volumetric process-understandable by non-experts	“The process becomes volumetric. We can model a room and present it to the client. That gives them confidence of how something can work on a particular way.”
27	Visual precaution tool	“…a lot of those problems have to be solved with an expense on site and BIM is trying to reduce that cost.”

Table 12: Whole-life costing - Index, Interactions and Evidence from practice

Index	Interactions	Evidence from practice

28	Classes minimisation-cost savings	"BIM can improve the clashes within the construction because the Mechanical engineer will be more aware of what the architectural drawing will look like. If they sort it out in the BIM model in the first place, then when then they actually build it they will get the services around the installed components because they will know about it."
29	Cheaper check of alternative solutions	"Future-proofing is possible with BIM and it will enable us to model a building with different given parameters more quickly and cheaply than otherwise."
30	Reducing the cost of resources	"In your BIM model you could have those scenarios and you could then optioneer those and check what is the most efficient way to provide a space now which meets most of those scenarios with the least additional cost [of resources]."

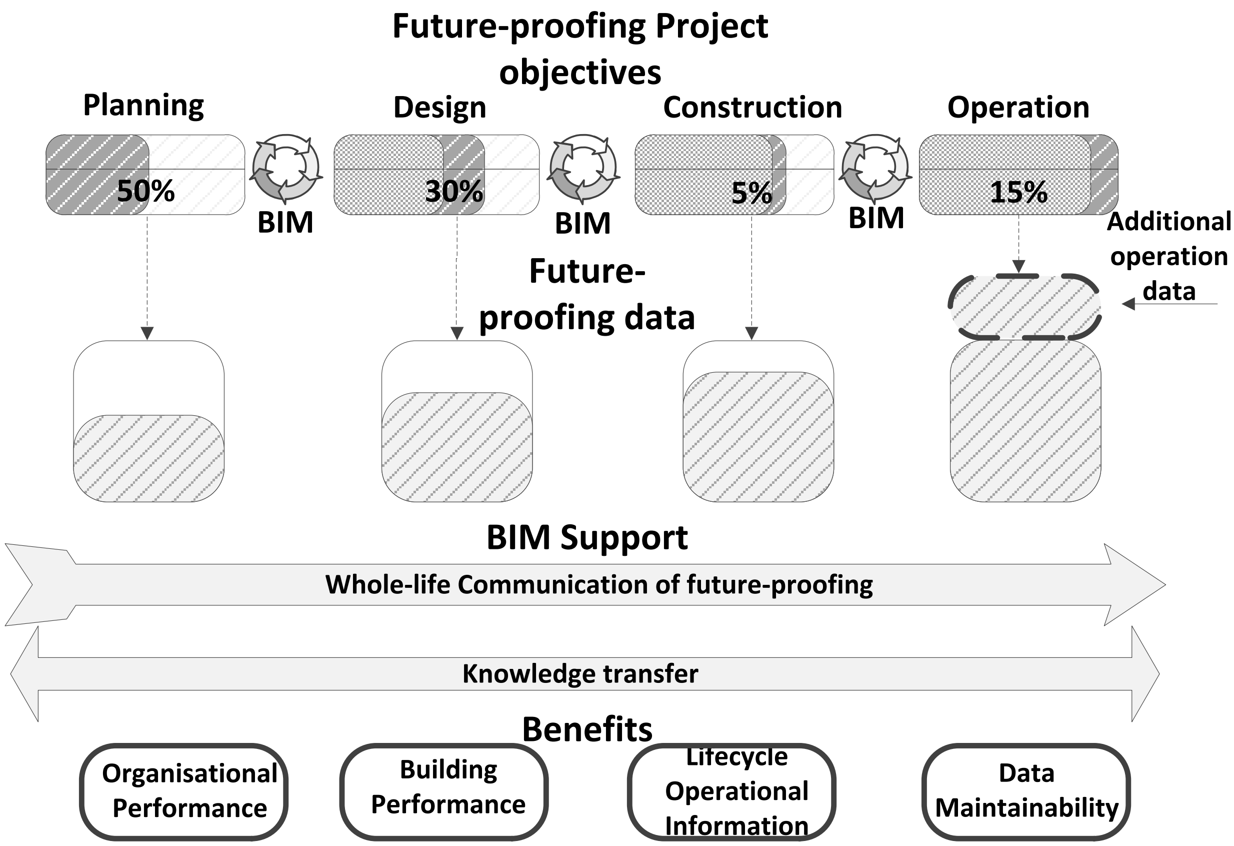

Figure 1: Benefits realisation for implementation of future-proofing using BIM

APPENDIX F

Research title:

Redefining the designer's role in optimising space flexibility and standardisation during healthcare facility refurbishment using Building Information Modelling (BIM)

Purpose of Survey

I am currently undertaking doctoral research into using BIM to design for space flexibility and use standardisation during the refurbishment of healthcare facilities and would like to elicit your opinion about healthcare space design. The results of this questionnaire survey will help to shape the future of my doctoral research in this area. **Aim of research**: Is to explore key factors that can enhance the designer`s role when designing space flexibility during healthcare refurbishment using BIM.

Targeted respondents are architectural designers, healthcare planners and BIM users. This questionnaire should take about 20 minutes to complete.

Data collected will be treated as confidential and will be used only for the purposes of this research. Anonymity of individuals and organisations will be maintained.

Notes for completing the questionnaire

- Please complete this questionnaire and email it back by **2 weeks**.
- There are four sections in this questionnaire
  - A. Background information
  - B. Designing **flexible** healthcare space
  - C. Standardisation of healthcare space
  - D. Flexible space design with **BIM**

School of Civil and Building Engineering, Loughborough University, Epinal Way, Loughborough, LEICS, LE11 3TU.

Section A (Background information)

A1. What profession most relates to your main roles? (Please tick all boxes that apply).				
Architect	BIM user	Planner	Academics	Other: please specify

A2. How many years have you been using BIM? (Please tick one box).				
0 year	1 – 5 years	6 – 10 years	11 – 20 years	Over 20 years
A2.1. How many years have you worked on healthcare design? (Please tick one box).				
0 years	1 – 5 years	6 – 10 years	11 – 20 years	Over 20 years

A3. On what percentage of your projects do you use BIM? (Please tick one box).				
1-20 Percent	21-40 Percent	41-60 Percent	61-80 Percent	81-100 Percent

A4a. Indicate your involvement in the following type of projects. (Please tick all boxes that apply).		
Type of projects	**Frequently**	**Some extent**
1. Commercial		
2. Industrial		
3. Residential		
4. Institutional		
5. Healthcare		
6. Other: please specify		

A4b. Please state your main roles in any of the following type of projects.	
Type of projects	**Your role (e.g. Chief Architect)**
1. Commercial	
2. Industrial	
3. Residential	
4. Institutional	
5. Healthcare	
6. Other: please specify	

Section B (Flexible healthcare space design)

Neufville et al, (2008) described flexibility as an alternative to future accomplishment, which can be switched on or off when required. It is the ability to be adaptable, variable or responsive to changing conditions to some extent.

B1. Please identify the six areas/spaces in a hospital that change most rapidly. (Rank in the highest order please)

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____

B2. Please state the four most important stakeholders making decisions during the design of "flexible healthcare spaces". (Rank in the highest order please)

1. ____
2. ____
3. ____
4. ____

Neufville, R. D., Lee, Y. S., and Scholtes, S. (2008). Flexibility in Hospital Infrastructure Design. Paper presented at the IEEE Conference on Infrastructure System.

B3. Please state the three design principles for achieving space flexibility.

1. ____
2. ____
3. ____

B4. Please state the three most important factors for architectural designers to consider when designing "space flexibility" during healthcare facility refurbishment. (Rank in the highest order please).

1. ____
____
2. ____
____
3. ____
____

B5. Please indicate (with an X) the degree of effectiveness of the following concepts when designing "flexible healthcare spaces".

Different types of flexible design concepts	Degree of effectiveness					
	Highly Effective	Effective	Neutral	Don't Know	Ineffective	Highly Ineffective
1. Modular designs						
2. Shell spaces						
3. Flexible curtain walls						
4. Flexible furniture and equipment						
5. Multipurpose foundations.						
6. Flexible partitions or moveable internal walls						
7. Other, please specify:						

Section C. Healthcare space standardisation

A standardised space can be defined as: *"formulation, publication, and implementation of guidelines, rules, and specifications for common and repeated use, aimed at achieving optimum degree of order or uniformity in a given context, discipline, or field" (Business Dictionary, 2011)*, for example, rooms or spaces are specified in standards such as the Healthcare Building Notes (HBN) and the Activity Database (ADB).

C1. Please state the four most important stakeholders making decisions during the selection of the most effective standards in healthcare projects. (Rank in the highest order please)

1. ____ 2. ____

____

3. ____

4. ____

C2. Please state the three key issues used in selecting the most effective standard from available standards. (Rank in the highest order please)

1. ____

____

2. ____

____

3. ____

____

____

C3. Please indicate your opinion. Standardisation impedes flexible healthcare space opportunities by providing specifications that could: (Please tick one of the boxes that apply).

(Standardisation) ↓	Some of the time	Most of the time	Not sure	Don't know	Not at all
1. Create rigid spaces/layout.					

2. Produce interrelationships of spaces that are highly complex.					
3. Hinder modularity concept layout.					

Section D. Building Information Modelling (BIM)

BIM is defined as *a tool and process (Eastman et al, 2011),* space flexibility can be improved with the use of BIM to model. *Jayaraman and Whittle, (2007)* states that visualisation and modelling *"allows stakeholders to explore "what if scenarios" as a way to test completeness and correctness*"

D1. Please identify the six BIM software that are used for modelling "flexible healthcare space" in your organisation.

1. ______ 3. ______ 5. ______ 2. ______ 4. ______ 6. ______

D2. Please indicate your rating of BIM's effectiveness in the analysis, evaluation and modelling the design of "flexible healthcare space" to inform decision for short-term and long- term basis.

Time basis ↓	Highly Effective	Effective	Neutral	Don't know	Ineffective	Highly Ineffective
Short-term basis						
Long-term basis						

D3. Please indicate the degree of effectiveness of using "what if scenarios" with BIM in the design of "flexible healthcare spaces".

Time basis ↓	Highly Effective	Effective	Neutral	Don't know	Ineffective	Highly Ineffective
Short-term basis						

Long-term basis						

D4. Please state the three most important issues to consider when modelling "flexible spaces". (Rank in the highest order please)

1. ____

____

2. ____

____

3. ____

____

D5. How does creating flexible space design with "what if scenarios" affect the BIM work flow process between architectural designer and fellow BIM collaborators?

Fellow BIM collaborators For example. "Interior decorators"	**Effect on BIM workflow** For example: "Using "what if a scenario" enables designers to send variable room sizes to the interior decorators and to receive possible fittings specification from them more rapidly".
1. Estimators.	
2. Mechanical Electrical and Plumbing (MEP).	
3. Structural engineers.	
4. Contractors.	
5. Other. Please specify:	

1. Oxford Dictionary [Online] Available from: http://oxforddictionaries.com/definition/flexibility. [Accessed on: 13th July, 2011]. 2. Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R., Liston, K., (2011). BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors, Canada. John Wiley and Sons. 3. Whittle, J & Jayaraman, P 2007, 'MATA: A Tool for Aspect-Oriented Modeling Based on Graph Transformation', Paper presented at MoDELS Workshops, 1/01/00, pp. 16-27.

D6. Please indicate your degree of (dis)agreement that "BIM tools hinder design innovation and creativity".					
Strongly Agree	Agree	Neutral	Don't know	Disagree	Strongly Disagree

D7. Please indicate the effectiveness of BIM use when modelling, analysing and evaluating facility space:						
Flexible facility space: ↓	Highly Effective	Effective	Neutral	Don't Know	Ineffective	Highly Ineffective
A. Expanding						
B. Contracting						
C. Relocating						
D. Adapting						

D7a. Please state the two most important considerations for sharing information within an organisation using BIM, such as between (architectural designer- architectural designers). (Rank in the highest order please)

1. ____

____

2. ____

____

D7b. Please state the two most important considerations for sharing information with an external organisation using BIM, such as between (architectural designer-architectural designers). (Rank in the highest order please)

1. ____

____

2. ____

____

D8. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice within an organisation.

1. ____

____

2. ____

____

D9. Please state the two possible methods/strategies of sharing findings/design knowledge through BIM in current practice with external organisations.

1. ____

____

2. ____

____

* * * * * * * * * * * *

Thank you for taking time to complete this questionnaire.

Please return it to **Ahmad M Ahmad** by email: **a.m.ahmad@lboro.ac.uk**.

Department of Civil and Building Engineering, Loughborough University, Ashby Road, Loughborough, Leicestershire, LE11 3TU

Phone: +447767757705; Fax: +44(0)1509 223981

If you wish to receive a summary of the results of this questionnaire, kindly tick here … ☐

Name: ____________________ Address: ____________________

Tel: ____________________ Email: ____________________

Kindly tick here…. ☐ If you are available to participate in a face-face/ phone interview, please provide your contact details above.

Thank you very much for your time and effort.

APPENDIX G

Document
HA BIM Programme BluePrint - 2014 - 2.1 - Approved
Employer Information Requirements V2.1
BIM Execution Plan V2
WI 325: Work Information Lot 1 - BIM
A42 J13 to M1 Major Maintenance RPB paper
M1 J23 to J24 Major Maintenance RPB paper
IAN 184/14
IAN 182/14
BIM Programme Dashboard - Sample
HA BIM Communication Strategy
Asset Data Management Manual Provider Requirements MAC Edition v1 1
Asset Data Management Manual ASC X Edition v 1.7_APPs
Asset Data Management Manual ASC X Edition v 1 7_REQs
Asset Data Management Manual ASC X Edition v 1 7_INTRO
Area 9 Watchman Plan
ADMM Roadmap
Management Plan 2015/16 (AIG)
CAW Programme Project Dossier
Highways Agency BIM Programme
SP 2.01 – inspect Asset Condition Role Activity Diagram
SP 2.01 – Inspect Asset Condition Role Activity Note
SP 2.04 – Manage Asset Data Role Activity Diagram
SP 2.04 - Manage Asset Data Role Activity Note
Area_10_AMOR_v1_7
Annex 25
Annex 6
Annex 26
Annex 15
Annex 20
COBie 4 EA
Plan of Work Alignment
HD 28
HD 29
HD 30
Task 399c Phase 2a_Data Management Strategic Advice 1
T-TEAR_Task242_Final Report_v1.0_ISSUED_28-05-14
IAM-IS_SchemaMap_v2
CW003 IAM IS Configuration Workbook - Assets - Prod - 29_Jan_2015 V1 0
HE_Uniclass_2015_Comments
Template-HA EIR-V3
Asset Data Management Manual ASC X Edition v 1 7_INTRO
Asset Data Management Manual ASC X Edition v 1 7_REQs
Asset Data Management Manual ASC X Edition v 1.7_APPs
Audit_Provision_Within_Contracts
SQR_Manual

APPENDIX H

Project:	BIM and future-proofing asset management		
Subject:	Document Level COBie / Asset Data		
Date and time:		Meeting no:	8
Meeting place:		Minutes by:	
Present:		Representing:	

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
1	**Document Level COBie** GT introduced the implementation of COBie developed with the Environment Agency. This addresses the documents to be delivered at all the milestone 3ea-4325-b8a3-7824f866ebb0).html" actors, ext, discipline, or field" (Business Dictionary, 2011cus of the previous Bentley / HA COBie workshop). Document COBie could encompass the Project Control Framework, Employers Information Requirements / Plain Language Questions, the Digital Plan of Works and the Master Information Delivery Plans. The client can specify in a matrix the PLQs that are relevant to each stage and the deliverables that are required to meet them, with levels of detail. An analysis of the PLQs vs. deliverables can show up both gaps and redundancies. This specification generates a COBie file of the requirements, which can be used to validate the suppliersi requirement to meet the completeness of data submitted. The suppliers deliver a COBie file that describes their documents. The geographic extent of the contents referred to by the document (drawing, report etc.) is given by a 2-point bounding box. The COBie can thus be computer-validated in several ways.		
2	**Asset Data** The introduction of Document COBie does not remove the need to work towards full COBie information exchange as part of the Drop 6 work as more automated methods become available. However, development of COBie solutions at asset-level will take significant time in specification and		

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
	development. But the needs of projects starting now will not be able to wait. A pragmatic way forward that is available almost immediately is to hand over asset data in formats that are easily generated by the suppliers, and easily imported by the asset databases. The obvious format is CSV, which is already in use and is non-proprietary. However, any such delivery of CSV documents would be recorded and controlled through the COBie process outlined in section 1 above.		
2.1 2.1.1	**Proposed changes to facilitate delivery** Set the requirement for all supplied Location data to be XY coordinates (in OSGB36). Calculation of Section Chainage and XSP from XY to be an internal routine after receipt by AIG. This has benefits in consistency of results; ability to retain accuracy from design / as-built / point-cloud survey; ability to re-set XSP or chainage of existing assets to match upgraded layout (e.g. conversion to Smart Motorway).	For SMP and other imminent projects	Proposals to be approved by BIM Programme Board and agreed as feasible by AIG
2.1.2	ADMM already has a Source ID field for all asset codes. Its purpose is not explained in ADMM, but was described by JJ as a code assigned by the suppliers. (This is inconsistent with sign post SGPO, which requires the Source ID of each sign face SGFA). Either provide a supplier ID, or change the data type of Source ID from Number to Varchar2 (text), to allow a project-unique ID to be assigned through the design and construction phases		
2.1.3	For the unique ID to be human-readable, it should combine the asset code, some BS1192 har2 (text), to allow a project-unique ID to be assigned through the design and construction phases post SGPO.		
2.1.4	Include this ID as first column of all CSV deliverables. Include columns for XY coordinates (for both start and end of continuous assets), and each required attribute. The Status Code from the draft XX Information Delivery Plan (IDP) could also be included as a column. All column headers to be draft XXX Information Delivery Plan (IDP) could also be include that CSV files in this form can be readily attached to 3D models in tools such as Navisworks, so will also be available through the design and construction stages.		
2.1.5	Not all asset types have codes in ADMM (Motorway Communications equipment, for example). The recent survey workshop (07/04/2015) identified a list of asset types and assigned codes to the missing ones. The minimum requirement is to have codes for		

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
	everything being designed and constructed. It would be highly desirable to have a list of attributes to match them in ADMM style.		
Other notes			

General – that the supply chain deliver as Graham suggests –
Use Document level COBie to list all the information that will be delivered about a project, including reports, drawings, and importantly, CSV files of the asset data currently required by ADMM. Essentially we are doing what "we" already do, but using COBie as a register of the information transferred.
Specifically
2.1.1 - The supply chain use the process of "boxing" all of the assets in line with process laid out by GT to define their geometric extent, and supply this information to NDD (or it's delegated maintainers). Essentially this will mean that NDD (or it's delegated maintainers) will need to process that geometric information to assign Chainage and XSP to assets.
2.1.2 - The next proposal consists of amending / clarifying the use of the Source ID field in ADMM so that it can be used by ADMM as a "anchor" point enabling ADMM users to be able to trawl back and access additional information about an asset over and above the basic information requirements of ADMM – this is in line with Jame's vision of the use of this code at our meeting in Elms house on the 26th March.
2.1.3 – HW then provides some recommendations on what he sees the Source ID being changed to, with the suggestions being eminently logical
2.1.4 - HW then recommends that the current CSV spreadsheets that are delivered to NDD (or it's delegated maintainers) have
o the relevant Source ID as the first column,
o An X and Y coordinate as the second and third "columns" for point assets
o An x and Y coordinate as the fourth and fifth columns for continuous assets (this then defines the box that "contains" the asset)
o A "status" code from the draft Highways England Information Delivery plan as the sixth column
o This then provides a practicable method for providing a rich model for a project, ie one that has the geometry linked to asset data.
2.1.5 – HW then recommends that the good work done at the Birmingham COBie workshop is continued and expanded to close the missing asset code gaps that were identified.

In summary

This approach means that there will be additional (useful) columns in CSV's of asset data that come from supply chain – I can see no reason why this would be a problem, unless we have automated processes for handling these CSV's (I don't believe we do).
Upon first inspection, there is no reason that this cannot be applied to requirements of MAC's and ASC's and so should become part of the strategy for NDD BIM
I believe HW's approach to the Source ID field aligns with James Aspirations for it's use in ADMM – need to check with the current ADMM owner that they have not decided on another use for it.

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
The process of using 2 point boxes for spatially arranging assets will create post-processing work for NDD (or it's delegated maintainers) – Note that currently the IAMIS Schema appears to have has the ability to accept xy data for 46 asset types already – how this should be approached (whether to extend /alter the schema or develop a processing routine to translate XY into Chain and XSP) should be a key part of the NDD BIM strategy			

Project:	BIM and future-proofing asset management		
Subject:	Possible new data route through whole life / Obstacles		
Date and time:		Meeting no:	4
Meeting place:		Minutes by:	IK
Present:		Representing:	

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
	The discussion was unstructured, but is summarised in topic streams		For discussion by Programme Board
1	**A possible new data route through whole life**		
1.1	Designers identify the assets that will be tracked in IAM-IS and other HA databases (Note: HP has since obtained the current IAMIS Data book from AIG)		
1.2.	For each proposed new asset Designers to assign new unique names. Naming derived from IAN184 file name *fields* in form AssetCode-*project-volume-location-number-*counter		
1.3	For existing assets identified from surveys, the existing unique IDs are reattached in order to update the relevant databases. These assets may subsequently be retained, relocated, destroyed or abandoned. (Note: efforts are ongoing to rationalise Lidar survey codes to make linking with IAMIS easier)		
1.4	Designers generate property data as unformatted tables (eg CSV files). Files named to IAN184, so show Originator code and PIN.		
1.4.1	The first column contains the assigned or recovered unique IDs		

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
1.4.2	The first row contains Column headers as database-ready property names (no spaces and all		
1.4.3	different) Where properties correspond to IAM-IS attributes, the column header to match the required name as		
1.4.4	given in the IAM-IS Workbook Other data such as quantities to be included for costing, procurement etc Contractors supply their properties (installation dates etc) against same unique IDs in separate		
1.4.5	files with their originator codes. Manufacturers similarly to add any relevant data in another separate file		
1.5	(Note: hyperlinks to specifications may be appropriate here, possibly in a standardised format) IAM-IS to store the assigned unique ID (as well as		
1.6	its own internally generated one). This maintains possible links to geometry in BIM models or their source CAD. (Note: this capability already present in IAM-IS, but		
1.7	not included in the standard CSV data transfer format)		
2	**Obstacles to methodology proposed in 1**		
2.1	UK BIM Task Group requirement for COBie No instruction yet for IAM-IS to incorporate COBie		
2.1.1	import No commercial software yet exports COBie		
2.1.2	Referencing methodology very unclear, especially if linear referencing to be used, eg carriageway		
2.1.3	section chainages (Note: IAMIS uses ITN GIS layers for background mapping. It is unclear how geographically correctly continuous assets will be displayed.) COBie cannot be attached to current BIM federation software eg Navisworks, Bentley Navigator (but spreadsheets, CSV etc can) Commercial solutions mostly generate internal property data. All these would need data export		
2.1.4	capabilities to required format. Some disciplines still missing from ADMM Asset class codes needed at the very least, even if		
2.1.5	not scheduled for incorporation in IAM-IS IBI Group may have made some for their laser survey work (Note: Harry attends meetings of the Laser group		
2.2	as link with BIM board)		
2.2.1	Suggestion to contact Inderjit Holwell (HA owner of ADMM) for advice.		

ITEM	DESCRIPTION & ACTION	DEADLINE	RESPONSIBLE
	(Inderjit.Holwell@highways.gsi.gov.uk)		
2.2.2	IAM-IS data requirements error-prone Locations by carriageway section + XSP require manual input Automated conversion from XY against new node-and-link network model gives link chainages but no		
2.2.3	offsets Only ends stored for linear assets in IAM-IS. No current means of holding intermediate shape.		
2.3			
2.3.1			
2.3.2			
3	**Possible solutions**		
3.1	Find minimum acceptable implementation of COBie, eg minimum acceptable implementation.		
3.2	Continue to use CSV files for property data delivery (as instructed in IAN182), but enhance		
3.3	their capability and formalise their layout		
3.3.1	Supply location references in National Grid coordinates only		
3.3.2	Add functionality to IAM-IS to derive any required linear reference and XSP from coordinates as part		
3.4	of data import Add functionality to report locations in any		
3.5	IAN99/07 local grid, or WGS84 (GPS coords), as		
3.6	well as National Grid.		
3.6.1	Add means to store defining 3D line for continuous assets, not just the end points. (JJ advised fairly easy to add facility for 2D proprietary ShapeFiles, as used in Envis) Add cross-section shape library to IAM-IS for linear assets. Complete asset code list for all disciplines, including those not scheduled for IAM-IS These should match the Survey Standard Code List for Lidar extraction		

APPENDIX I

A study of the concept of future-proofing in healthcare building asset management and the role of BIM in its delivery
Introduction

Research is currently being undertaken into using BIM to future-proof healthcare facilities by integrating space standardisation and flexibility. I (ilias) would like to elicit your opinion about the concept of future-proofing in the decision/construction process.

Aim of study: to identify attributes in future-proofing healthcare facilities during the design and/or construction process and identify the role of BIM.

Targeted respondents are Healthcare construction professionals (procurers and suppliers) whose work is related to future-proofing of healthcare facilities. Data collected will be treated as confidential and will be used only for the purposes of this research. Anonymity of individuals and organisations will be maintained.

There are three sections in this interview session:

A. Background

B. Future-proofing Healthcare facilities

C. The role of BIM in future-proofing Healthcare facilities

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A. Background

1. What is your profession?

Client specific ☐ Architect ☐ Consultant (e.g. Struct. Engineer) ☐ BIM ☐ Specialist Construction Manager ☐ Other (please specify) ☐

2. Experience

	Never	0-5 years	6-10 years	11-15 years	over 16 years
a. How many years have you been working on healthcare projects	☐	☐	☐	☐	☐
b. How long have you been using ADB?	☐	☐	☐	☐	☐
c. How long have you been using BIM processes/tools?	☐	☐	☐	☐	☐
d. How long have you been using Codebook?	☐	☐	☐	☐	☐
e. How long have you been using Activeplan?	☐	☐	☐	☐	☐
f. How long have you been using Other? (please specify) ☐	☐	☐	☐	☐	☐

B. Future-proofing

3. What does **future-proofing healthcare facilities** mean to you.
4. What are the main **barriers** to future-proof healthcare facilities?
5. How does future-proofing **impact** on the design/construction process?
6. What are the **current and future drivers** for future-proofing?
7. What are the main **criteria for space substitution**?
8. How do you estimate the **cost of change on refurbishment** projects?

C. Future-proofing and BIM

9. Were there **any limitations regarding the use of BIM (tools/processes)** in applying future-proofing?
10. How does future-proofing **benefits from the utilisation of BIM**?
11. How does **BIM impact (policy/technology/process)** the application of future-proofing?
12. What are the **current and future drivers of BIM** in the application of future-proofing?

THANK YOU