The Delusion of Innovations?

An investigation into micro-level factors to an effective macro-level diffusion of Building Information Modelling in the UK

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A thesis submitted in partial fulfilment of the requirements of Edinburgh Napier University, for the award of

Doctor of Philosophy

June 2021

For my Nana, Alice.

Your intelligence and love of books have always been, are, and always will be an inspiration to me. I hope that in dedicating this thesis to you, your brilliance can live on forever. I miss you dearly.

DECLARATION

I declare that this thesis presented for the degree of Doctor of Philosophy has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgement, the work presented is entirely my own.

[redacted] 18/06/2021

Signature Date

ACKNOWLEDGEMENTS

I would like to take this opportunity to give my sincerest gratitude to all who have supported me throughout this journey. This thesis would simply have not been written without the intellectual, emotional, mental, and, at times, physical (!) support of you all.

First and foremost, thank you to my supervisory team for your wisdom and for the provision of sound advice over the years. To Prof John Currie for your optimism, guidance, pep-talks, contacts, and beer. To Dr. Andrew Brown for your friendship, counsel, and encouragement to follow this path in the first place. Your unfaltering belief in my abilities provided me with the courage to continuously make that leap into the unknown. You both have been invaluable pillars of support over these past few years.

Thank you also to my exam team: to Prof Sean Smith for his role as Independent Panel Chair throughout my studies, to Prof John McDougall as Chair during my Viva, and to Dr. Suha Jaradat and to Prof Mike Pitt as my Examiners. I wish to also extend my gratitude to Peter KK Lee, as this PhD would simply not have been possible without your generous donation.

A special thanks is reserved for those in E21, who were always more than just colleagues and I can safely call lifelong friends. Your comradeship made a typically lonesome journey one filled with strength and community.

Thank you to BIM Academy, for providing me with an opportunity to put theory into practice and for helping me start a fulfilling career in all things BIM.

Finally, I wouldn't have completed this research if it wasn't for the love and support of my family and friends outside of university, particularly my mum, my dad, and my brother, Alastair. We've all been through a lot during my studies, but you have never once let that hold me back. And, of course, to Dave, who came into my life at the right time, believed in me, and got me across the finishing line.

Thank you all, from the bottom of my heart.

Abstract

Building Information Modelling (BIM) is being hailed as the digital enabler to reform of the traditionally stagnant construction industry, with the UK leading much of the global drive to strategize the macro-level adoption of BIM. However, in an inherently competitive environment borne from the heterogeneous, project-based nature of the industry, there is a risk that a disjoint may exist between rhetoric and reality. Furthermore, data from commercial studies suggest that barriers to effective macro-level diffusion may instead lie at the micro-level (i.e. individuals) rather than at the meso-level (i.e. organisations and projects) which has formed much of the focus in literature to date. In addition, recent efforts have begun to employ technological innovation adoption, borrowed from the Information Systems (IS) research domain, as a theoretical lens through which to study BIM adoption. However, this presents BIM adoption as a false dichotomy. This study departs from this fallacy by appraising BIM as a systemic innovation comprising people, process, and technology constituent elements. The adoption and assimilation of BIM therefore requires practitioners to develop a myriad of competencies, *inter alia*: hard skills, (e.g. how to interact with BIM-enabled tools), soft skills, (e.g. how to collaborate efficiently), and knowledge of the fundamental components underpinning the digital workflows. In an industry with a renowned dysfunctional training delivery model and a world with increasing reliance on internet-based, unstandardised knowledge acquisition, it is crucial to consolidate the role of BIM competency with adoption rate assessments.

The research problem is a need to better understand the efficacy of BIM adoption and utilisation, using interacting levels of analysis, within the context of the AECO industry's strained relationship with reformation and digitsation, and the UK's position as a leader in the global BIM rhetoric. Neglect to consider this assimilation efficacy has the potential to impact on the ability to realise the purported benefits driving the UK's BIM agenda, such as meeting key sustainability targets and industry transformation. Therefore, using an established BIM adoption taxonomy, this study explored and investigated the role and potential impacts of micro-level factors on achieving an effective macro-level diffusion of BIM in the UK. Using Pragmatist philosophical principles with abductive reasoning, the present research employed an exploratory sequential design in which a qualitative phase preceded and informed a quantitative second phase. Phase I employed an extensive literature review to explore the narrative that a so-called "assimilation gap" effect may be influencing perceived levels of BIM adoption. These findings were augmented by two semi-structured focus groups comprised of a heterogeneous range of BIM-related experts. Drawing on technological innovation diffusion and system success theories, a comprehensive conceptual framework was then developed to investigate the relationships between perceived and actual use of BIM, its antecedent factors, and its adoption outcomes. The developed model informed Phase II, which utilised an online questionnaire survey for data collection, and descriptive and Partial Least Squares Structural Equation Modelling (PLS-SEM) techniques for analysis.

The qualitative findings support the narrative proposed by the study that existing adoption measurement and upskilling procedures regarding BIM diffusion within industry are insufficient. The conceptual model is then empirically tested and refined by the quantitative results. This thesis argues that the efficacy of systemic innovation adoption and assimilation should be considered from a multi-level perspective, rather than attempting to understand diffusion using dichotomous, meso-led measures. Several theoretical contributions are made, including: ascertaining the roles of perceived and actual use in innovation adoption research, developing a bespoke instrument for competency assessment derived from the UK BIM standards, and reinforcing the importance of existing, innovation-based concepts within construction applications. This study also provided a gateway to establishing a robust BIM assimilation and use assessment framework by challenging the current UK diffusion and policymaking model and its effectiveness in a digital world.

Table of Contents

List of Figures

List of Tables

Glossary

Assimilation refers to the process of adoption which transitions the user from simply acquiring the innovation to fully embracing it.

Building Information Modelling is a process which applies object-based modelling to develop a structured dataset for managing a built asset across its life-cycle.

Classical Test Theory is the dominant approach to measurement scales by assuming the observed score is the sum of an individual's true test score and a degree of random measurement error.

COBie is a non-proprietary data format and international standard used to deliver non-graphical asset information from building information models.

Determinant is defined within the Unified BIM Adoption Taxonomy as an item used to measure a latent factor.

Diffusion is the term pertaining to the successful spread of an innovation at the macro-level.

Driver is defined within the Unified BIM Adoption Taxonomy as the term given to a collection of variables which are theorised to share an underlying theme.

Exploratory Sequential Design is a mixed methods research design in which an exploratory, qualitative study precedes a descriptive, quantitative study in a two-stage process.

Factor is positioned within the Unified BIM Adoption Taxonomy as a latent variable measured by several determinants.

Factor Analysis is a data analysis technique used to define a dataset's factor structure by identifying and grouping determinants with strong correlations.

Implementation is the term pertaining to the successful adoption of an innovation at the micro-level.

Innovation is a concept which is perceived as novel to the adopter.

Item Response Theory is an item-centric test theory approach to measurement by using the items' properties to identify the relationship between a latent trait.

Macro-Level is the level of analysis pertaining to the industry or network scale.

Meso-Level is the level of analysis pertaining to the project or organisation scale.

Micro-Level is the level of analysis pertaining to the scale of a team or individual.

Partial Least Squares is a component-based estimation approach which assumes an iterative approach to parameter estimation to maximise the explained variance.

Structural Equation Modelling is a multivariate analysis technique used to simultaneously test multiple dependence relationships between latent constructs.

Systemic Innovation is a concept which is novel to the unit of adoption, but requires network-level adoption to be diffused effectively.

Chapter One

Introduction to the Research

Innovation adoption research has been a core focus of the Information Systems (IS) domains for decades. The body of research surrounding our cognisance of innovation adoption is growing and adapting as technologies become more complex and embedded within our social systems. However, more recently, emphasis has shifted as the world moves towards a ubiquitous digital reality and factions which were previously considered less innovative are now at the forefront of academic efforts to homogenise digital growth and opportunities for everyone.

This chapter discusses the context to the study which focuses on the need for radical innovation within the UK Architecture, Engineering, Construction, and Operations (AECO) industry. It then justifies the research by identifying the gaps in knowledge within the developing area of Building Information Modelling (BIM) and its emerging synergies with general innovation adoption studies. The development of the overall research aim and its objectives are then presented, together with a brief description of the research design and the methods adopted. The theoretical and practical contributions of the study to the fields of BIM adoption and industry reform are then briefly explored, before concluding with a brief outline of the thesis structure.

1.1 Research Context and Background

The Architecture, Engineering, Construction, and Operations (AECO) sector captures a profoundly diverse set of activities which span the entire lifecycle of a built asset, from its inception, through to maintenance and operation, and ultimately its decommissioning and demolition. By its very nature, the sector's output is highly heterogenous, ranging in size and complexity from inter alia simple housing projects to multifaceted infrastructure and portfolio projects (Dainty, Moore, and Murray, 2006). Projects can also be characterised by the subsector in which they fall (i.e. whether it is a commercial and social, residential, or infrastructure project), what type of works are involved (i.e. new-build, refurbishment, or mixed), and whether the works are funded by the public sector or privately procured (Cabinet Office, 2011).

The structure of the sector is also extremely diverse: for example, over 99% of construction businesses within the supply chain trade are small and medium enterprises (SMEs), i.e. comprise of less than 250 employees (Cabinet Office, 2011; Infrastructure and Projects Authority, 2016; BEIS, 2020) and 96.3% of which are microbusinesses which comprise fewer than 7 employees (Office for National Statistics, 2019). In addition, the multidisciplinary nature of the sector denotes that a wide range of job roles are available, each with varying skills types and levels. Broadly speaking, job roles and disciplines can be split into three subsectors: (1) the construction contracting industry, (2) the provision of construction related professional services (e.g. architectural services, leasing of construction equipment, etc.), and (3) the manufacturing of construction related products and materials (Department for Business Innovation & Skills, 2013).

The sector's vast scope therefore lends itself to playing a significant role in contributing to the UK economy. In 2017, the UK construction industry[1] alone contributed 6% of GDP and approximately 2.184 million workforce jobs (Office for National Statistics, 2018).

However, as a key determinant of economic growth, labour-productivity figures, as measured by financial output per hour, indicate that the construction industry has remained the least productive industry in the UK economy for over two decades (Office for National Statistics, 2018). In addition, labour-productivity growth is monitored as an indication of sector and broader economic health because of it being a direct influence on policy to increase GDP per person (Office for National Statistics, 2007). However, as shown in Figure 1.1, the sector is disproportionately lagging behind the growth of other industries and the whole economy. Furthermore, Figure 1.1 demonstrates that the sector is volatile and highly susceptible to fluctuations within the wider economy. As a high-risk, high-cost sector with considerably low profit margins, labour-productivity growth is thus more

[1] Under the UK's Standard Industrial Classification (SIC) 2007, the AECO sector is difficult to define and quantify in its entirety. Rather, the construction industry within governmental statistics is usually defined in accordance with Divisions 41 to 43 inclusively, or Section F, of the SIC2007 (Office for National Statistics, 2009). However, this focuses predominantly on trades and omits manufacturing of construction products and professional activities, such as architecture and quantity surveying. The contribution to GDP and employment numbers would therefore be higher if these activities were included (Cabinet Office, 2011).

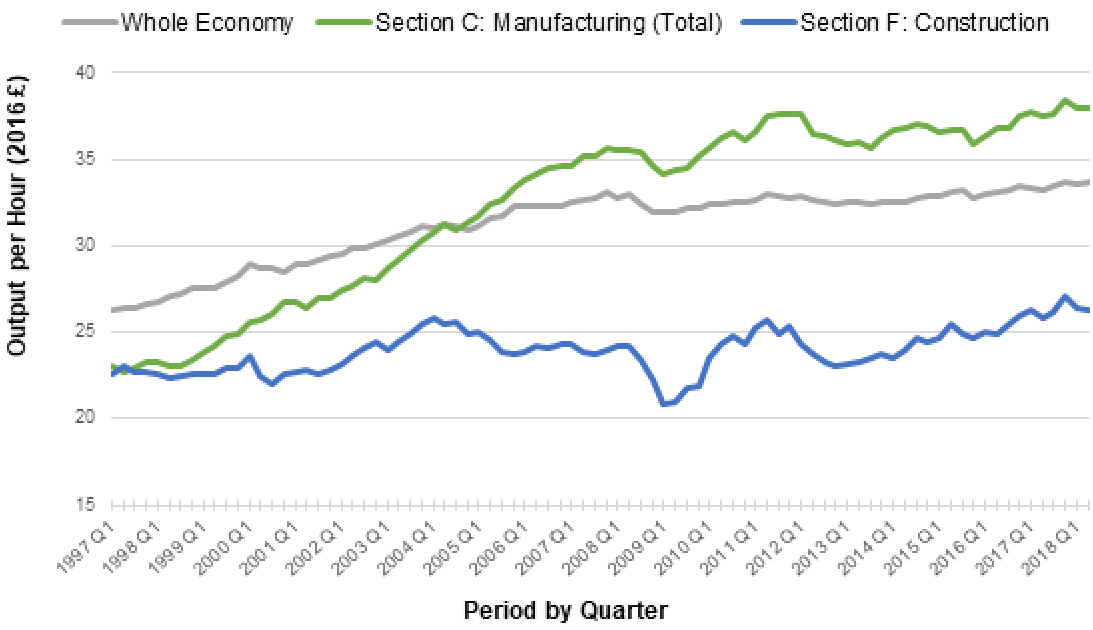


Figure 1.1 Contribution to Labour Productivity by Industry - Chained Volume Measure. Data from Office for National Statistics (2018)

sensitive to falters in financial investment (Crotty, 2012; Farmer, 2016).

Struggling labour-productivity growth rates in the AECO sector is a global issue: construction productivity growth has averaged 1% a year over the past two decades worldwide whereas the total world economy and global manufacturing sector averaged 2.8% and 3.6% respectively (Barbosa et al., 2017). Whilst the UK has seen better rates – construction: 5.9%, UK economy: 6.3%, manufacturing: 8.2% - labour-productivity in the construction industry is still exhibiting slower growth when compared to other sectors (Farmer, 2016; Office for National Statistics, 2018). This indicates that whilst the sector is recognised for its significant contributions to the UK economy, there remains untapped potential for the sector's value, and thus GDP, if its labour-productivity could improve.

1.1.1 Ongoing Efficiency Issues

As an issue with a long-documented history, the suboptimal labour-productivity rates may be a symptom of the UK's often-criticised approach to the design, construction, handover, and operation of built assets. The subsequent inefficiencies which occur within these processes have been repeatedly articulated in a succession of notable publications calling for reform, such as the Wolstenholme (2009), Egan (1998), and Latham (1994) reports. Despite an 80-year history of reviews and recommendations, with the earliest being published as far back as the mid-1930s (Bossom, 1934), the recent Farmer report (2016) still echoed consistently reoccurring themes. These ongoing criticisms are often grounded within the multifarious, competitive configuration of the sector, which has led to a high degree of fragmentation within the supply chain and its customer base. This is despite its project-based nature which fundamentally calls for inter- and intra-organisational collaboration.

Rather, due to the temporary nature of construction contracts and heavy reliance on sub-contracting, contemporary projects are often a product of adversarial environments (Dainty, Moore, and Murray, 2006; HM Government, 2013). This is having a twofold effect on delivery to the detriment of the client; (1) the unpredictability of projects is compromising the ability for projects to be delivered to budget and within the scheduled timeframe (Bourn, 2001; Crotty, 2012; Farmer, 2016), and (2) there is a broad consensus that buildings do not perform as intended in operation when compared to designed performance (Usable Buildings Trust, 2014). This has led to an ongoing, heavy stigmatisation of the UK's industry and its capacity to deliver value to the client. More concerningly, a poor industry image has serious implications, not least for employment rates and labour-productivity growth (Farmer, 2016).

There's no doubt that the UK Government and its public bodies should play a leading role in an industry reform as clients; the Latham report identified that "Government should commit itself to being a best practice client" (Latham, 1994, s.1.17) whilst the Egan report suggested that "Government [should] commit itself to leading public sector bodies towards the goal of becoming best practice clients seeking improvements in efficiency and quality" (Egan, 1998, p.5). Public-sector construction represents a significant portion of the industry - as much a quarter (Cabinet Office, 2011) - thus has the potential to act as a catalyst for change.

The UK Government Construction Strategy (GCS) was subsequently published in 2011 as a response to the ongoing stagnation of the industry (Cabinet Office, 2011). Similar in contents to that of its predecessors, the GCS provided a somewhat damning account of public-sector construction and called for a profound change in how its public bodies and their suppliers approach their projects. The intention of the GCS was twofold: (1) for the Government to better itself as a construction client, and (2) to challenge current industry practices, focusing primarily on cost reduction and developing enhanced business collaboration models.

Nevertheless, the findings in the GCS cannot be considered ground-breaking; stark parallels can be drawn between the aspirations identified in the earlier reports and the 2011 Strategy. For example, the Egan discourse highlighted that industry fragmentation could hinder performance improvement measures because of the high number of firms practicing within the UK (Egan, 1998). This was echoed by the GCS, which also identified that there is a fragmentation issue within the public sector as a client; individual departments procure separate contracts thus appearing as separate clients to suppliers (Cabinet Office, 2011).

The dominant strand running through the calls for reform lies in the requirement for new, consistent procurement models which are built on integrative, collaborative working delivery models. However, the challenge facing the UK construction industry is tied into ensuring the failures of the Strategy's predecessors are not repeated. This was highlighted by the Wolstenholme report (2009) who found that the objectives identified by Egan (1998) were merely being intermittently adopted. This indicated a sub-par response to the urgent call for reform, despite evidence from demonstrative projects highlighting that significant benefits could be derived from employing Egan's client-driven delivery model. Rather, Wolstenholme found that best practice was only being conducted on flagship projects rather than becoming a business-as-usual approach for the wider sector.

1.1.2 Building Information Modelling: A Change Enabler?

To stimulate effective change, a radical, centrally-driven innovation was required which would not only address the strategic objectives set out in the GCS, but also be a robust and achievable solution for the entire sector to adopt and achieve. The findings and recommendations from the GCS paved the way for the introduction of a fully integrated

Building Information Modelling (BIM) approach into the UK's public-sector projects (Cabinet Office, 2011). BIM represents a holistic approach to the procurement, design, construction, and management of a built asset through the exploitation of structured, digital data. Seen as the progression into digital construction technology, the capabilities inscribed within BIM are widely believed to have a revolutionary impact on addressing the challenges faced by the AECO industry (Bryde, Broquetas, and Volm, 2013). For example, Crotty (2012) believes that the low-quality, unstructured information used within the contemporary project setting is to blame for project unpredictability and the sector's low profitability, arguing that BIM uses reliable computable data to therefore overcome the industry's shortcomings.

Whilst arguably still a relatively nascent development, BIM purports to use the fundamental principles of integrating people, processes, and technology to deliver quantifiable savings, thus contributing to a more efficient industry (Arayici et al., 2011b; Lu and Li, 2011; Hanafi et al., 2016; Liu, Nederveen, and Hertogh, 2017). BIM also facilitates the practices of effective information management and enhanced stakeholder engagement, enabling better relationships to exist within the supply chain and between suppliers and clients. The BIM objective set out in the GCS is underpinned by this perceived potential, inscribed into a hypothesis as: "Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information" (BIM Industry Working Group, 2011, p.97).

The fundamental principles of BIM practice echo the drivers of change identified by Egan (1998), which were derived from observations of the manufacturing and service industry. BIM uses digital technologies and a shared platform to "integrate the process and the team around the product" (Egan, 1998, p.13) and the standards-driven approach which has been adopted by the HM Government builds on "a focus on the customer" (Egan, 1998, p.13) . The heightened importance of information management within BIM is also redolent of the Latham report, which suggested that the practice of co-ordinated project information is necessary for client engagement and meeting the client's needs (Latham, 1994). The introduction of BIM has now been explicitly woven into refreshed calls for reform and has been identified as a *critical change agent* for the industry (Farmer, 2016). More recently, BIM now forms many of the underlying principles which support the recommendations of the Farmer report (2016) and the Hackitt report (2018), the latter of which comprised a review of the building regulations following the Grenfell Tower fire tragedy in London in 2017.

Extending beyond the boundaries of the public-sector and the remit of the GCS, an umbrella report was produced which consolidates the themes raised by Latham and Egan and the strategies identified within the GCS to measure and benchmark the improvements within the wider built environment (HM Government, 2013). The Construction 2025 strategy proposes the following target:

- 33% reduction in the initial cost of construction and the whole-life costs of built assets,
- 50% reduction in the overall time, from inception to completion, for newbuild and refurbished assets, and,
- 50% reduction in greenhouse gas emissions in the built environment.

Following the introduction of BIM into the Government's agenda in 2011, industry and academia have been producing evidence which is effectively demonstrating BIM's contribution to achieving savings in increased productivity and reduced failure costs across industry, (e.g. Bryde, Broquetas, and Volm, 2013; Eadie et al., 2013a) and towards validating the Government's own hypothesis (Cabinet Office, 2015). Although less quantifiable evidence exists surrounding BIM's contribution to lower emissions, Construction 2025 states that "only through the implementation of BIM will we be able to deliver more sustainable buildings, more quickly and more efficiently" (HM Government, 2013, p.9).

The time and cost savings attributed to an effective BIM approach are typically only beneficial to individual clients on a project-by-project basis. However, environmental benefits, such as the improved sustainability credentials and reduced energy performance of a single built asset, are most valuable when considered within the context of the wider built environment. This is because the built environment represents a significant target area for policymaking efforts in the fight against climate change; it contributes up to 40% of global energy use in developed countries (Pérez-Lombard, Ortiz, and Pout, 2008; European Commission, 2010) and as much as one third of the global greenhouse gas emissions overall (Sustainable Buildings & Climate Initiative, 2009). If tackled appropriately, as much as 90% of the building sector's emissions can be reduced (European Commission, 2011). However, a parallel can be drawn between the criteria for a successful industry efficiency reform and for real reductions to be made in emissions in accordance with energy policy and under the remit of Construction 2025. Its success relies on a combined effort being made across the entire sector, rather than achieving best practice and exceptional sustainability credentials within single crevasses of the built environment. This therefore suggests that the ability to align current reform efforts with achieving the emissions reduction target relies on an effective sector-wide adoption of BIM.

1.1.3 Digital Innovation and Upskilling in the AECO Sector

The acceptance and effective adoption of BIM presents an additional challenge for the AECO sector: notwithstanding the seemingly industry-wide recalcitrance towards effective cultural change, the GCS found that the sector has failed to exploit growth opportunities, particularly in terms of adopting digital technologies (Cabinet Office, 2011). This is supported by data measured by the McKinsey Global Institute's Industry Digitization Index (McKinsey Global Institute, 2015). This suggests that the construction sector is lagging behind all other sectors in its relative level of digitisation; it features last out of twenty-two sectors within Europe (McKinsey Global Institute, 2015) and comes second bottom only to the agriculture and hunting sector in the U.S. (McKinsey Global Institute, 2016).

Likewise, a report reviewing the level of digitisation in UK businesses found that whilst basic digital technology is now nearly ubiquitous across all sectors, wider adoption of more advanced digital technology is generally lower in construction-based businesses (Mack-Smith et al., 2016). The report also identified that digitisation as a low business priority was a barrier for the effective utilisation of digital technology for as much as 98%

of construction-based firms. In addition, the low profit margins in which AECO firms operate restrict investment into R&D activities, training, and tool purchasing for digital technologies, particularly if they are considered to be an innovative approach with little evidence of Return on Investment (ROI) and are thus high risk (Egan, 1998; Farmer, 2016).

However, evidence demonstrates that there is a positive relationship between digitisation and productivity: at a local level, ICT-intensive businesses tend to enjoy effective, beneficial business process changes and higher levels of productivity (Mack-Smith et al., 2016). The relationship between placement within the Industry Digitization Index and productivity growth also suggests that investment into digital technologies would provide a significant portion of the much-needed productivity gains at the sector level – see Figure 1.2. Accordingly, this influence of digitisation on productivity growth further supports the government-driven advocation of digital construction in a sector seemingly restricted in adopting progressive technologies.

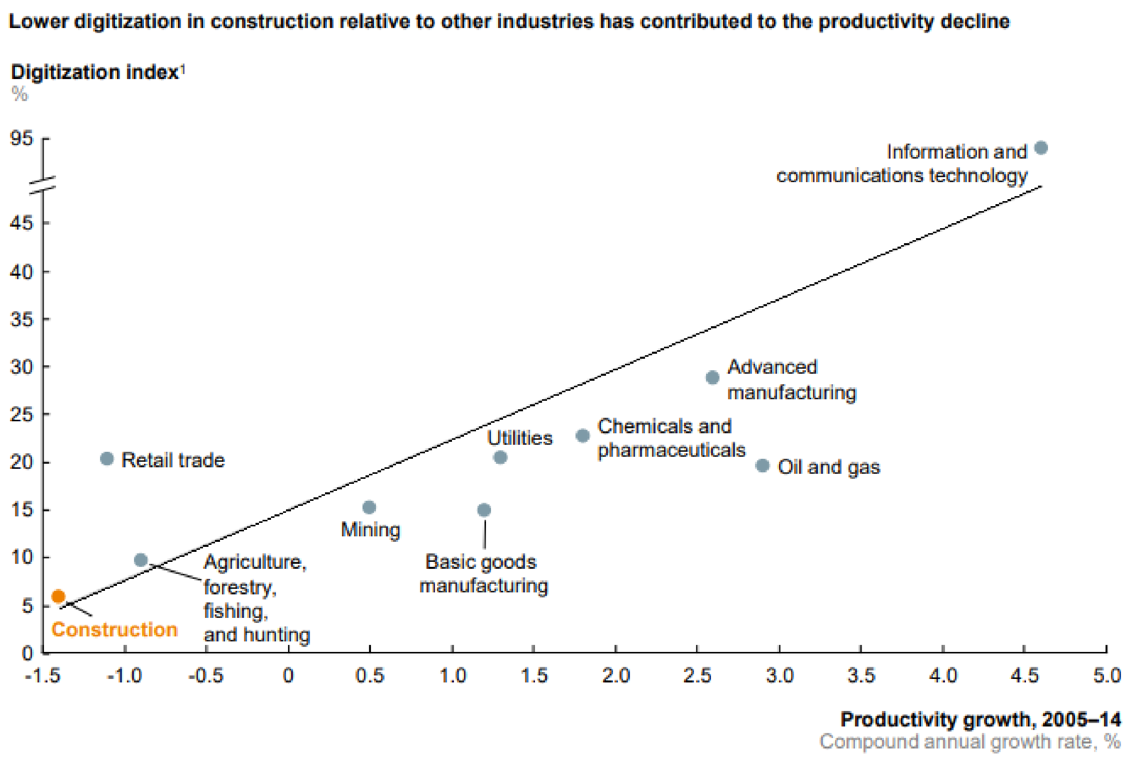


Figure 1.2 Relationship of placement in the MGI's Digitization Index and Productivity Growth, adapted from McKinsey Global Institute (2017)

In line with its poor history of digitisation, the GCS had criticised the sector's infrastructure for its inability to support collaborative working in a digital environment and for hindering the widespread adoption of a suitable technology to support this (Cabinet Office, 2011). However, digital technologies are continuing to become more sophisticated in intelligence and interface as well as generally accepted in everyday life, leading to a robust springboard for the development of digital infrastructure within the AECO sector. Furthermore, as BIM has become a mandated requirement in certain facets of the sector, software vendors are advancing their semantic object modelling and data federation capabilities to facilitate the digital collaboration demands required by BIM. Likewise, standards bodies are producing technical standards to support the technological processes, workflows, and roles inscribed by this new, digitally-enabled method of working (e.g. British Standards Institution, 2013; International Organization for Standardization, 2018).

A government-supported innovation is therefore advantageous for endorsing initiatives in the development of the process and technology constituent elements of BIM. As a source of external pressure, the barrier of low business priority can also start to be removed for organisations. However, as a softer concept, the people element in the constituent triad which comprises the BIM model is less tangible than its counterparts. Moreover, this is reflected in general BIM literature in which the prevailing focus is on the development of specialised tools and frameworks to streamline BIM adoption within an organisational or project setting(e.g. Arayici et al., 2011b; Lee, Park, and Won, 2012; Motawa and Carter, 2013; Won et al., 2013; Sackey, Tuuli, and Dainty, 2015; Cavka, Staub-French, and Poirier, 2017; Gurevich, Sacks, and Shrestha, 2017; Papadonikolaki, 2018), or the development of a "BIM-based" tool in response to a specific technical issue within the design and construction workflow (e.g. Martins and Monteiro, 2013; Wong and Zhou, 2015; Yarmohammadi and Ashuri, 2015; Soust-Verdaguer, Llatas, and García-Martínez, 2017; Zhang et al., 2017). This is likely due to the ability to measure the implementation and consequences of a determinate variable in a specific, monitored setting.

However, BIM adoption requires fundamental process changes to occur in a coordinated manner across multiple, interdependent disciplines within a single project setting, outside of process and technology considerations. In other words, whilst the digital infrastructure is continuing to evolve, sector culture – i.e. the shared social behaviour of people – needs to adapt alongside it for BIM to be effectively adopted. To this end, BIM is a systemic digital innovation (Taylor and Levitt, 2005b; Lindgren, 2016; Hall, Algiers, and Levitt, 2018). Whilst this is explored in more depth in Chapter TWO, it is worth noting that systemic innovations tend to diffuse more slowly and not as widely across project-based sectors (Taylor and Levitt, 2004b).

The inability to enact a culture shift has blighted the AECO sector for decades. Nevertheless, the introduction of a government-driven innovation generates a unique opportunity to revise how culture is cultivated through the need to upskill industry practitioners. As a multifaceted systemic innovation, the adoption and assimilation of BIM requires existing and future practitioners to develop a myriad of new competencies, inter alia: hard skills, (e.g. how to interact with BIM-enabled tools), soft skills, (e.g. how to collaborate efficiently), and knowledge of the fundamental components underpinning the digital workflows.

Although the sector is extremely heterogenous and exposure to the various BIM components will vary according to the individual's job role, discipline, and skill level, a basic, common level of understanding will be necessitated across the industry to support a standard degree of performance and widespread adoption. In an industry with a renowned dysfunctional training delivery model (Farmer, 2016) and a world with increasing reliance on internet-based, unstandardized knowledge acquisition (Designing Buildings Wiki Ltd, 2017), it is therefore crucial to consolidate the often-neglected role of upskilling with adoption rate assessments.

1.2 Justification for Research

The political advocation and demonstrable potential of widescale BIM adoption provides a strong foundation for industrial and academic research to develop a robust, evidence-based adoption and assessment strategy which ties into a renewed education and training provision model. This section therefore discusses previous research within this area, the influences of the UK's BIM strategy, and the central research problem.

1.2.1 PREVIOUS RESEARCH

A plethora of BIM adoption studies are starting to appear in the general BIM research domain. Therefore, the present study needs to be contextualised within this emerging field. From a preliminary review of the literature, previous research broadly falls into three camps:

- **Commercial adoption surveys:** Commercial attempts to gauge adoption, whilst enjoying high response rates and the ability to assume a longitudinal perspective by conducting surveys annually, often lack methodological rigour and instead exist as an indicative measure. Notable commercial adoption surveys include McGraw Hill Construction (2014), the National Building Specification (NBS) National BIM Survey (2020), Construction Manager's *BIM+* magazine (Chevin, 2020), and, most recently, the UK BIM Alliance (2021).

- **Analysis adoption within a specific setting:** Often scholars assume a narrow perspective and focus on adoption within a defined boundary, such as a project setting or within an organisation. This can produce rich insights and tailored strategic decisions but can also restrict applicability to the wider sector and therefore have limited impact on policy. Studies focusing on BIM and innovation adoption within an organisational setting include Arayici et al. (2011b), Won et al. (2013), Poirier et al. (Poirier, Staub-French, and Forgues, 2015), Rogers et al. (2015), Sackey et al. (2015), Juan et al. (2017), Ayinla and Adamu (Ayinla and Adamu, 2018), Buć and Divjak (2018), and Troiani et al. (2020). Studies focusing on BIM and innovation adoption within a project setting include Taylor and Bernstein (2009), Davies and Harty (2013b), Eadie et al. (2013a), Cao et al. (2014a), Merschbrock and Munkvold (2015), and Papadonikolaki (2018).

- **Studies which draw from IS theory:** An emerging body of literature is beginning to draw from the abundance of frameworks and conceptual models within IS innovation adoption literature to clarify the thinking behind the adoption process of BIM practitioners. However, these studies place too much emphasis on the technological aspects which results in insufficient attention being paid to other influential factors, such as environmental and organisational characteristics. This somewhat trivialises the nuanced interpretation of BIM as a complex innovation. Examples of such studies include Davies and Harty (2013a), Cao et al. (Cao et al., 2016), Howard et al. (2017), Lee et al. (2017), Dowsett and Harty (2018), Gholizadeh et al. (2018), Hilal et al. (2019), and Qin et al. (2020).

However, common to all camps, very few studies consider the role of assimilation and the implications of macro-scale adoption and upskilling. Moreover, this builds into our understanding of BIM as a systemic innovation as novel concepts will therefore be required as to stray from the typically assumed dichotomous grasp of adoption; too often adoption is treated from a "either you do BIM, or you don't" perspective when reality dictates that adoption requires building blocks which reflect the multi-constituent nature of BIM.

Furthermore, studies tend to focus on the introduction of BIM to developing countries such as Saudi Arabia (e.g. Almuntaser, Sanni-Anibire, and Hassanain, 2018), China (e.g. Herr and Fischer, 2017; Jin et al., 2017), India (e.g. Ahuja et al., 2016; Ahuja et al., 2020), Pakistan (e.g. Bhatti et al., 2018), Ghana (e.g. Acquah and Oteng, 2018) and Nigeria (e.g. Abubakar et al., 2014), or developed countries which are only just recently considering BIM adoption at a coordinated national level, such as Canada (e.g. Poirier, Forgues, and Staub-French, 2017; Brunet et al., 2018) Ireland (e.g. Mcauley, Hore, and West, 2017), Australia (e.g. Davies, McMeel, and Wilkinson, 2017), and within the wider European Union (Charef et al., 2019). This is instead of delving into the nuances of well-developed strategies in countries such as the UK. Therefore, to situate the present study within this developing body of knowledge, the key driver for this research is predicated on the influential capacity of the strategies currently employed within the UK.

1.2.2 The Influences of UK BIM Strategies

Within the UK context, the BIM rhetoric is being expressed primarily through a top-down dynamic in which its adoption is being driven and enforced by politically supported mandates (Fenby-Taylor et al., 2016; Kassem and Succar, 2017). The political structure and devolution of the individual governments within the UK resulted in the development of separate strategies; Her Majesty's Government (HMGov.) governs the initiatives and policies for centrally-procured projects in England and the wider UK context, whilst the Scottish, Welsh, and Northern Irish Governments devised their strategies based on their own public-sector capabilities and project scope. As the first to introduce a mandate for the adoption of BIM on their own projects, HMGov. assumed a leading role within the UK by establishing much of the groundwork for a robust national strategy template. This included facilitating the development of a comprehensive suite of standards and tools which provides a unified understanding of the fundamental structures and terminologies supporting BIM adoption.

The significance of the UK-based strategies within the global BIM movement provides an additional but crucial stratum in the justification for building on the extant BIM adoption research. As part of the preparation for Scotland's mandate, the Scottish Futures Trust (SFT) undertook a global study which evaluated BIM policy in eleven countries around the world (Fenby-Taylor et al., 2016). The SFT developed a mathematical variable, known as the Ease of Integration Index, which enabled the national efforts to be quantified and compared based on the ease of executing policy within each country, particularly within the context of digitisation and BIM. The variable considered policy, governance, and economical factors of each country. The study found that Scotland and the UK were placed third and fourth respectively in the rankings behind Singapore and Norway, indicating the strength of the countries' policymaking influences.

The core tenets underpinning the UK's strategies have become an internationally-recognised model for other nations to adopt and adapt. For example, the Bew-Richards maturity "wedge", as seen in Figure 1.3 (on the next page), has been used as a guide for introducing a stepped approach to BIM adoption using defined levels of maturity in many other contexts (e.g. Rogers, Chong, and Preece, 2015; Herr and Fischer, 2017; Herr and Fischer, 2019; Ayinla and Adamu, 2018; Koseoglu, Sakin, and Arayici, 2018). The influence of the UK-based standards can also be seen internationally; in late 2018, the move to transition the UK's suite of standards into international standards began in which

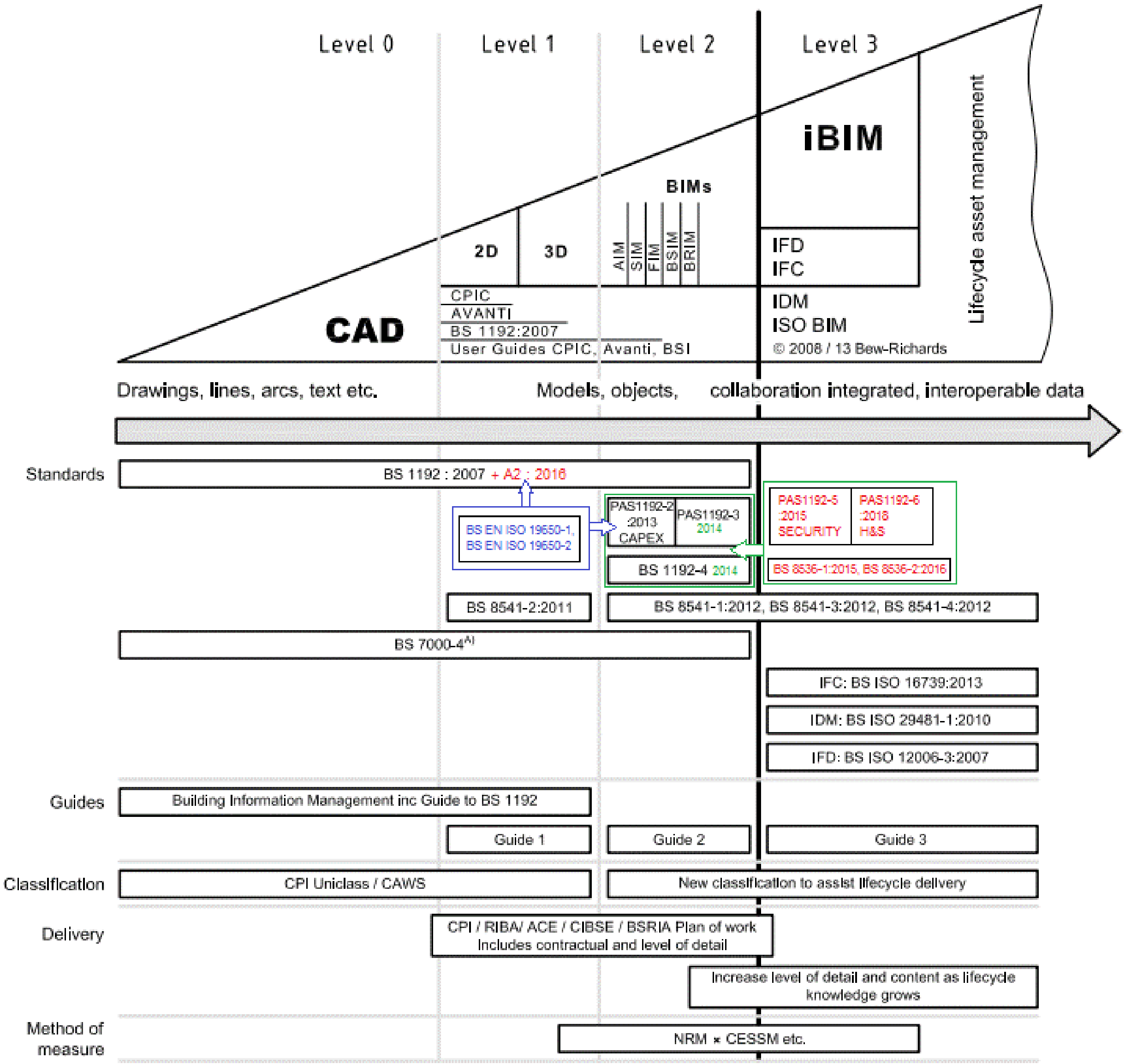


Figure 1.3 Bew-Richards Maturity Wedge. Adapted from BSI (2013) to include recent standard developments as highlighted by colour. Red = Developments since 2013. Green = the core 1192 suite. Blue = the 2018/19 ISO standards which supersede BS 1192:2007 + A2:2016 and PAS 1192-2:2013.

the initial two standards in the suite – BS1192:2007+A2:2016 (principles of creating collaborative information) and PAS1192-2:2013 (using BIM in the capital and delivery phase) – were superseded by International Organization for Standardization (ISO) publications. Aside from terminology changes, the principles enshrined within the resultant BS EN ISO 19650 standards remained the same as their predecessors, demonstrating the rigour of the original British Standards for use on a global platform. The suite has since expanded to encapsulate PAS1192-3:2014 (using BIM in the operational phase) and PAS1192-5:2015 (security-minded specification). The relevant standards and accompanying notes on their transition to BS EN ISO publications are provided in Appendix A.

The internationalisation of the suite also represented a key stage towards achieving alignment between Member States within the EU BIM Task Group. The Task Group was established in 2016 as a pan-European initiative and is coordinated by HMGov's Department for Business, Energy and Industrial Strategy (BEIS)[2] and funded by the European Commission. The Group aims to combine national efforts and to create a world-leading market by homogenising digital growth across the continent and demonstrating a unified leadership (EU BIM Task Group, 2016). As lead coordinator of the Group and originator of the demonstrably robust principles upheld in the ISO BIM standards, the strategies employed within the UK are therefore of great significance to the achievement of wider goals.

1.2.3 The Research Problem

The overall BIM journey is still in relative infancy, but the rate of effective diffusion across the globe relies on key enactors to guide BIM adoption using appropriate and rigorous vehicles for delivery. The UK is already demonstrating its role as a BIM pioneer through its direct involvement within European policy and through the influence of its world-renowned, centrally-driven strategies. Accordingly, it then becomes essential to gain an understanding of how BIM adoption is diffusing across all sectors within the UK to ensure the strategies are being implemented effectively. This is because neglect to consider this adoption efficacy has the potential to impact on the ability to realise the purported

[2] BEIS is formerly known as the Department for Business, Innovation and Skills (BIS).

benefits driving the UK's BIM agenda, such as meeting key sustainability targets and industry transformation as promoted by the Construction 2025 strategy (HM Government, 2013).

Therefore, the emergent research problem is a need to better understand BIM diffusion within the context of the AECO industry's strained relationship with digitsation and reformation, and the UK's position as a leader in the global BIM rhetoric. Moreover, existing research highlights a dearth in understanding adoption as a process of assimilation rather than a dichotomous activity. Therefore, this research seeks to open a dialogue regarding current measures of diffusion and how we interpret BIM adoption. In doing so, this research challenges the apparent efficacy of BIM diffusion in the UK in an effort to ensure that the nation remains a leader in the journey towards a digital world.

1.3 The Research Project

Whilst this chapter has provided rationale for conducting further exploration into BIM adoption research, the relative nascence of BIM in academia and in practice provides the present study with scope to adopt an emergent approach to project design. By doing so, the research can respond to findings as they develop, providing a dialogue between academia and real-world applications. Rather than dealing with the confines of a prescribed research problem, emphasis is then placed on the organic generation of research objectives as the study progresses and how they respond to the developing environment in which they are situated.

Nevertheless, in order to guide the direction of the research, and to build upon the groundwork laid within the context and justification sections of this chapter, the overarching aim is provided:

To explore and investigate the role of micro-level factors on achieving an effective macro-level diffusion of Building Information Modelling (BIM) in the UK.

1.3.1 Research Objectives

The four emergent objectives used to help achieve the research aim are stylised as RO1 to RO4 inclusively and are presented in Table 1.1.

Table 1.1 Research Objectives

Research Objectives	
RO1	To interrogate the perceived rate of BIM adoption from a multi-level perspective.
RO2	To critically review the most common models and theories related to Information Systems (IS)-based innovation acceptance, assimilation, and use by appraising their contributions and applicability to BIM.
RO3	To develop and propose an integrative framework for micro-level BIM use behaviour.
RO4	To utilise the proposed model to analyse the influence of the identified micro-levels factors on BIM use behaviours.

1.3.2 Summary of the Research Design

The methodology underpinning the present study is grounded within the Pragmatist philosophical paradigm. This promotes the significance of the research objectives in shaping the research design and the subsequent utilisation of appropriate methods to address each. An exploratory sequential research design is employed, in which a qualitative Phase I precedes and informs a quantitative Phase II. Each Phase is briefly described below:

- In line with assuming an emergent approach to the project, Phase I is exploratory in nature. It consolidates the findings of the literature review and a focus-group interview to inform the groundwork for the generation of an appropriate theoretical framework. Collectively, Phase I aims to address RO1, RO2, and RO3.

- Phase II adopts a descriptive research design in which quantitative techniques are employed in the collection and analysis of data. Drawing from the developing domain of BIM adoption research using an IT/IS theoretical lens, an online questionnaire survey instrument is designed and distributed across the UK's AECO sector. Partial-Least Squares Structural Equation Modelling (PLS-SEM) are used to describe the causal relationships between the latent variables described within the generated model. Phase II attempts to address RO4.

1.4 Summary of the Research Contribution

The contribution of this research to knowledge within the domain of BIM is presented in Chapter NINE and summarised here:

- Theoretically, this research builds on attempts in previous BIM adoption studies to provide a critical review of the most common theories and models related to IS-based innovation adoption as applicable to BIM. Whilst appraising BIM as an innovation grounded in an IS setting provides nuanced interpretations of the adoption process, current efforts generally ignore the multifaceted nature of BIM and rather approach BIM adoption as a dichotomous decision: either the practitioner or organisation has adopted BIM, or they have not. Although such theories and models are robust and well-researched within the domain in which they were built, this study demonstrates that the analysis of BIM adoption requires considerations that are over and beyond those captured by these theories and models. The thesis therefore contributes to literature on the adoption of complex, systemic innovations over traditional simple technology applications.

- Methodologically, the study aims to build on the work of previous BIM adoption research and employ a predominantly quantitative-led approach to empirical data collection. To do so, the thesis uses the narrative set out by the literature review to construct and test an integrative model which is appropriate to the research context. In addition to utilising well-established IS-based constructs in a BIM setting, the model proposes novel relationships which can be empirically tested using the PLS-SEM approach.

- Finally, from a practical standpoint, the study builds on real-world applications and HM Government policy, which grounds the research in a UK-specific context. Moreover, the findings of the research aims to provide insights which can be used by policymakers and thought-leaders at the macro-level, and by decision-makers at the meso-level.

1.5 Structure of the Thesis

The narrative of the thesis is guided by a nine-chapter structure. The interrelationships between the chapters and the general logic of the thesis are demonstrated by a flow chart in Figure 1.4.

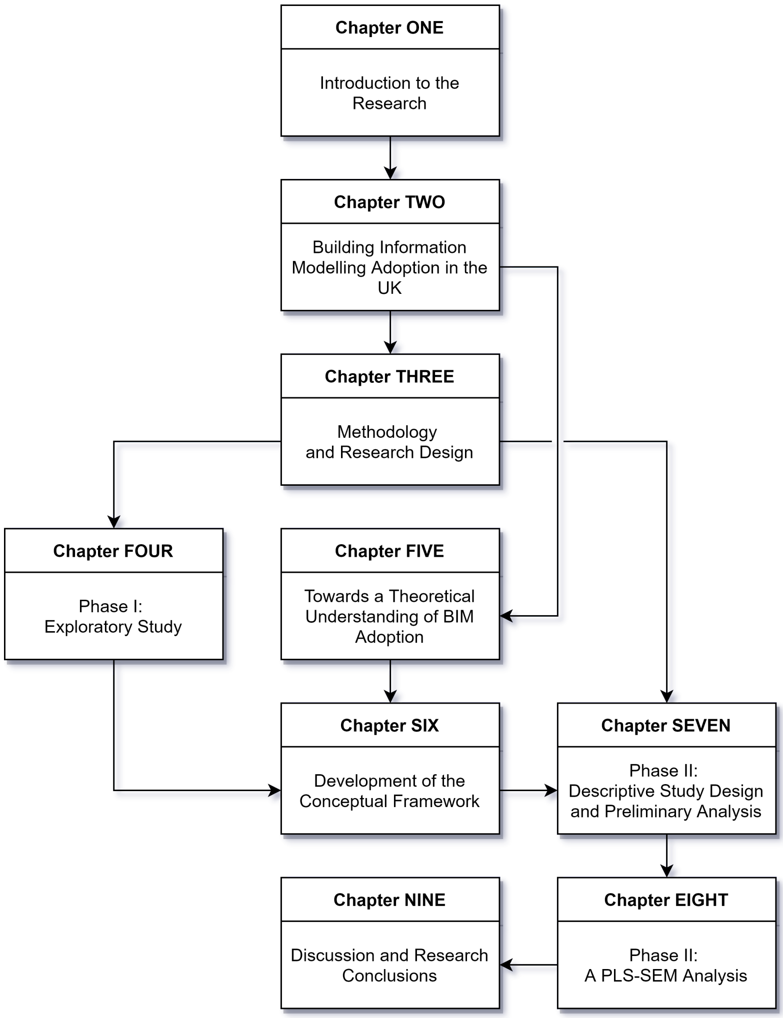


Figure 1.4 Outline of the thesis and relationships between chapters

This chapter, **Chapter One**, has provided the context to the study and lays the groundwork for the research project. This includes setting out the theoretical contributions of the research to the growing body of academic literature focusing on BIM adoption and the practical implications from a multi-level perspective. Furthermore, it has presented the research aim and its objectives. A brief overview of the research design has also been provided.

Chapter Two deals with the literature review. It explores the general emergence of BIM in construction research and the role it plays within the UK's AECO industry. The chapter focuses on the appraisal of BIM as a construction innovation and uses this lens to critically review the empirical findings of prior studies. Using an emergent approach to define the research problem, the literature review establishes the narrative for the overall thesis.

Chapter Three describes the methodological considerations underpinning the thesis and the decisions made in designing the data collection strategies. Several quantitative and qualitative methods are evaluated, and the adopted two-phase approach is described and justified with respect to addressing the research objectives.

Chapter Four uses the findings of the literature review to inform the first phase of the research design. The chapter deals with the empirical considerations surrounding the semi-structured focus group interviews and presents and analyses the qualitative data.

Chapter Five presents a critique of the current theoretical understanding surrounding BIM adoption. It briefly debates the challenges of employing a specified level of analyis and applying an IS-based theoretical lens to the study of BIM adoption. The chapter presents a review of several theoretical models and frameworks and discusses the rationale for developing a conceptual framework.

Chapter Six develops and presents the conceptual research model for the present study. It discusses the conceptualisation of the model constructs, using the findings of the exploratory study in Phase I and the review of existing theoretical models and frameworks in the previous chapter. The chapter also states the hypotheses to be addressed in Phase II of the study.

Chapter Seven outlines the data collection and descriptive analysis for Phase II of the present study. This chapter deals with the developing of the research instrument and the processing of the sample data. The descriptive statistics describing the basic features of the collected data are also presented.

Chapter Eight presents the data analysis and results of Phase II. The sample data and constructs are tested with regard to their reliability and validity, before a Partial Least Squares Structural Equation Modelling (PLS-SEM) method is adopted. The chapter also presents the empirical testing of all hypotheses and discusses the findings.

Chapter Nine presents the conclusions to the research and discusses how the four research objectives were met. Accordingly, the theoretical and practical contributions of the research are summarised in addition to an outline of the study's limitations. Future directions of the research are also suggested.

1.6 Concluding Remarks

Chapter ONE has set out the background of the research and serves as an introduction to the thesis. In doing so, it has justified the rationale of the study and presented the research aim and research objectives. A brief overview of the theoretical and practical contributions was then set out. This research intends to contribute to the growing body of literature focusing on BIM adoption by providing a novel perspective on emergent issues in the area. Chapter TWO will begin by presenting an extensive review of literature and building the narrative to support the investigation.

Chapter TWO

Building Information Modelling Adoption in the UK

This chapter presents the first of two literature review chapters. The chapter begins by exploring the terminology underpinning Building Information Modelling (BIM) by delving into its definition as an innovation and the role it plays within the technological evolution of the Architecture, Engineering, Construction, and Operations (AECO) sector. An overview of academic literature is then provided by drawing on a series of studies which have employed quantitative bibliometric methods. In view of systematically structuring a rapidly evolving research domain in line with the school of thought presented by these studies, key terms and concepts to be applied within the present study are defined. Using this taxonomy as the framework for the review, the chapter then seeks to gain an understanding of existing BIM adoption methods at the macro-level and identifies potential limitations by drawing on established work within the Information Systems domain to frame the research problem. The literature review concludes with a discussion of the BIM assimilation role and the efficacy of the present knowledge structure underpinning industry transformation.

2.1 BIM and Innovation in a Construction Context

As described in Chapter ONE, the widely articulated evidence documenting the numerous failed reform attempts indicates that the AECO sector has struggled to overcome its underlying inefficiencies and give way to effective innovation. This perception is exacerbated when viewed from a digitisation perspective; as other sectors appear to enjoy the potential offered by advanced digital technologies such as the deployment of e-commerce models and cloud computing facilities, the AECO sector remains reluctant to digitise to the same extent (Mack-Smith et al., 2016). Rather, innovative activities, such as the adoption of integrated project processes or more latterly digital technologies, have traditionally been restricted to selective pockets of excellence in the sector, as evidenced by Egan (1998), Latham (1994) and within the GCS (Cabinet Office, 2011). Furthermore, when assessed against other sectors, this digital recalcitrance translates to a stagnation in labour-productivity growth for the sector (McKinsey Global Institute, 2017). Therefore, to reinforce the tenet introduced in Chapter ONE, we require a significant paradigm shift to not only promote effective, uniform sector-wide change, but to do so by exploiting the capabilities of digital technologies to bring us in line with other sectors in the UK economy.

2.1.1 What is BIM?

The widely articulated evidence documenting the numerous failed reform attempts indicates that the AECO sector has struggled to overcome its underlying inefficiencies and give way to innovation. Subsequently the sector's journey of technological evolution is difficult to map beyond graduation from traditional drawing-board production to two-dimensional (2D) and then three-dimensional (3D) Computer-Aided Design (CAD). Whilst indeed transformational for the design of assets, the move to CAD processes likely occurred as an inevitable consequence of the embedding of digital technologies into wider society and daily life, rather than the unanimous adoption of a disruptive innovation. For example, universal acceptance of advancing computational powers enabled CAD to become a cheaper, faster, and ultimately indisputable alternative to manual processes.

These advances also supported the shift to the geometric modelling capabilities inscribed within 3D CAD processes. This also coincided with the emergence of the internet which enabled web-based communication platforms to be utilised to share and discuss project deliverables. However, very little changed when considering a project holistically; information was still exchanged using static, paper-based delivery mechanisms which were built on ill-informed business models and fragmented supply chains. In this sense, the computer offered the same outputs as the drawing board, only with greater efficiency associated with the ability to easily update, reproduce, and store electronic information being achieved within the contained boundaries of a design team.

As computer capabilities continue to advance and with extensive research efforts, the software industry has begun to migrate from CAD into parametric modelling which are today characterised as BIM tools or applications (Turk, 2006). This describes the extension beyond the three dimensions associated with CAD-based geometry to consider the embedding of associated non-graphical data and rules into parametric objects. The non-geometric data is commonly referred to as further dimensions, such as 4D representing scheduling data and 5D representing cost data. Without the ability to attach this information, the object is simply a graphical model which can only provide visual information to be interpreted by a human recipient. Rather, this data transforms the model into a rich data repository which in turn doubles as a virtual representation of the asset which can be 'constructed' like-for-like in a virtual space. In essence, creating and structuring information using parametric objects creates a single source of truth from which all outputs, whether geometric-based such as drawings and rendered illustrations, or non-geometric such as schedules or costing data, can be generated. This means any alterations made to the information, whether it is geometric or not, is then reflected in real-time across all associated data and generated outputs, thereby creating parametric integrity and overcoming many of the issues presented by CAD-based methods of working.

The concept of parametric modelling using objects is fundamental to understanding the foundations of Building Information Modelling (BIM). The origins of the term and its acronym are debated, but in studies concerning the evolution of BIM (e.g. Eastman et al., 2008; Li et al., 2017; Liu, Nederveen, and Hertogh, 2017; Santos, Costa, and Grilo, 2017; Hosseini et al., 2018) credit is generally given to the term initially being used in an academic publication by van Nederveen and Tolman (1992). However, it is often mooted that the concept has been around since the 1970s, with many of the notions we associate with BIM today being described in the works of Charles M. Eastman in 1974 (Eastman et al., 1974; Eastman et al., 2008). For example, Eastman described the application of a single integrated database for parametric design, enabling analyses to be conducted on, and outputs such as drawings to be generated from, a single informed dataset under the prototypical name of *Building Description System* (Eastman et al., 1974).

Nonetheless, the modern interpretation of the term only began to be popularised around 2002 following software vendor consensus on the terminology[1]. The popularity can be reflected in the volume of BIM-related academic publications, as illustrated in Figure 2.1, which have since been bolstered by the emergence of governmental mandates around the world.

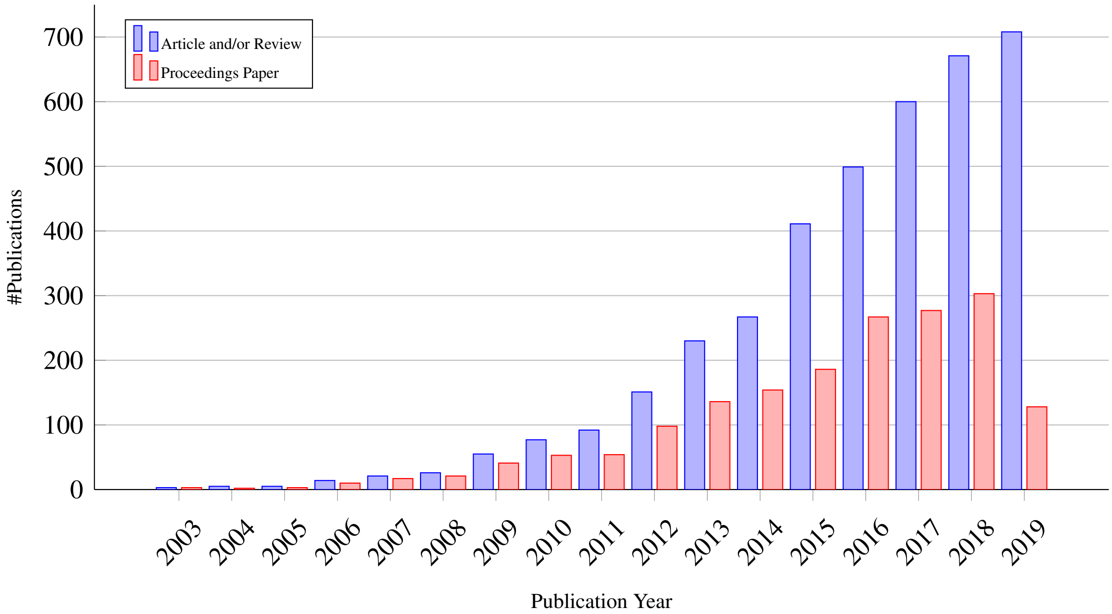


Figure 2.1 Number of BIM publications over time for the period 2003 to 2019 inclusively, by document type and year. Data from Web of Science (2020)

There is no one single, widely-accepted definition of BIM (Turk, 2006; Eastman et al., 2008; RICS, 2014). As demonstrated by the non-exhaustive list in Table 2.1, many definitions have emerged across numerous outlets and publications. Despite the range of sources and differing terminology, all broadly align in their core tenets: each draws on the use of digital technologies, the facilitation of collaborative workflows between project team members, and the use of these processes across the entire lifecycle of an asset. These commonalities are identified in Table 2.1 as blue, orange, and red text respectively. In addition, many definitions draw on a combination of interacting elements in an attempt to capture this inherently multifaceted nature in practical terms.

[1] Ambiguity still exists surrounding the exact terminology, such as whether it is a verb which refers to the process, or as a noun which refers to the artefact or model output (Eastman et al., 2008; Turk, 2006). In addition, the acronym was originally stylised by the BITG as BIM(M) to capture the inclusion of "Management" which is sometimes interchangeable with "Modelling" (BIM Industry Working Group, 2011). An alternative view was also proposed in a guidance note published by RICS (2014) in an attempt to delineate the conflicting terms as separate but equally valid elements under the umbrella of "BIM" as a concept: (1) the model or representation of the asset (the Building Information Model), (2) the process of developing the model (Building Information Modelling), and (3) the use of the model (Building Information Management). However, this is ultimately a matter of semantics.

Table 2.1 BIM definitions by source

Source	Origin	Type	Definition[a]
NBIMS (2020)	US	Website	Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.
NBS (2016b)	UK	Website	BIM or Building Information Modelling is a process for creating and managing information on a construction project across the project lifecycle. One of the key outputs of this process is the Building Information Model, the digital description of every aspect of the built asset. This model draws on information assembled collaboratively and updated at key stages of a project.
BIM Dictionary (2019)	Au	Website	Building Information Modelling (BIM) is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space.
CDBB (2020)	UK	Website	BIM is a collaborative way of working that facilitates early supply chain involvement, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets. BIM provides a digital representation of the physical and functional characteristics of an asset to support reliable decision making and management of information during its life-cycle.
Eastman et al. (2008)	US	Handbook	[BIM is] a verb or an adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation.
Sacks et al. (2018)[b]	US	Handbook	BIM [is] a modeling technology and associated set of processes to produce, communicate, and analyze building models. BIM is the acronym of "Building Information Modeling," reflecting and emphasizing the process aspects, and not of "Building Information Model."
Penttilä (2007)	Fi	Article	[BIM is] a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle.
Succar & Kassem (2015)	Au	Article	[BIM is] the current expression of construction industry innovation, a set of technologies, processes and policies, affecting industry's deliverables, relationships and roles.
Sackey (2014)	UK	PhD Thesis	[BIM is] the process of using the available technological artefacts to produce data-rich, object oriented and parametric representation of a facility on a digital platform which enables the various construction stakeholders to effectively use and reuse the model to coordinate, design, construct and operate a facility.

[a] Blue text = Reference to the use of digital technologies, Orange text = Reference to collaborative workflows between project team members, Red text = Reference to being applicable across an asset's lifecycle, Green text = Proposed foundational elements of BIM.
[b] This entry references the 3rd edition of the BIM Handbook and is provided as a comparison to the definition provided in the 1st edition (Eastman et al., 2008). Notable differences includes a renewed focus on the communicative element of BIM but removes any reference to the process extending beyond the capital delivery phase.

As highlighted in Table 2.1 by the green text, these elements are generally interchangeable between *processes, methodologies* or *ways of working*, *policies*, *technologies*, and *people*, with processes emerging as the dominant theme. BIM therefore constitutes a broad concept; although built on technology-centric principles enshrined within the transition towards parametric modelling, the introduction of BIM ultimately redefines how project teams interact and exchange information.

For the purposes of the present study and to somewhat delimit our understanding in practical terms, BIM will be defined according to the suite of British Standards (BS) guiding BIM adoption in the UK using the Bew-Richards Maturity Wedge (see Figure 1.3). These are briefly introduced in Table 2.2. A full list of BIM-related standards, including those which sit on the periphery of the recognised BIM Level 2 suite in addition to those developed under the UK BIM Framework, are provided in Appendix A.

Table 2.2 BIM Level 2 suite of British Standards (BS) and Publically Available Specifications (PAS)

Standard	Part	Year	Title
BS 1192	+A2	2016	Collaborative production of architectural, engineering and construction information. Code of practice.
	4	2014	Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice.
PAS 1192	2	2013	Specification for information management for the capital/delivery phase of construction projects using building information modelling.
	3	2014	Specification for information management for the operational phase of assets using building information modelling.
	5	2015	Specification for security-minded building information modelling, digital built environments and smart asset management.
	6	2018	Specification for collaborative sharing and use of structured Health and Safety information using BIM.

2.1.2 An Overview of BIM Research

Over the past decade, BIM has evolved to become a ubiquitous term within the global AECO sector. As illustrated in Figure 2.1, its growing dominance has generated significant interest within academic and industrial research. As an emergent but considerably established concept, this presents a unique opportunity to synthesise the current body of literature in an attempt to uncover key knowledge structures and research trends. In addition to the plethora of traditional literature reviews e.g. Gu and London (2010); Azhar (2011); Volk et al. (2014); Chong et al. (2017); Ghaffarianhoseini et al. (2017); Costin et al. (2018) a prominent branch of study has subsequently developed in recent years which provides a somewhat meta-perspective of the emergence of BIM in research. Although literature-based, these studies are typically quantitative and generally draw on statistical bibliometrics, such as those conducted by Yalcinkaya and Singh (2015), Zhao (2017), Santos et al. (2017), Li et al. (2017), and Hosseini et al. (2018). Whilst each study vary slightly in their methodological approach and overarching research objectives, they unanimously describe an ongoing, positive trend in the volume of BIM-related publications over time. For a cross-study comparison, Tables 2.3 and 2.4 present the literature-based data collection and analysis methods applied in each study respectively.

Table 2.3 Data collection methods for existing bibliometric studies

Study	Papers	Years	Database(s)	Keywords / Search String[a,b]	Additional Search Criteria
Yalcinkaya & Singh (2015)	975	2004-2014	*Unspecified*	1 = (“bim” AND “building” and “bim” AND “information modeling”) 2 = ("building information modeling" AND "bim")	1 = Phrase is included in Title, Abstract, and/or Author-Specified Keywords (980 papers) 2 = Phrase is included in full text (89 papers) 94 duplicates found and removed.
Li et al. (2017) Core Dataset	938	2004-2015	Web of Science (WoS)	TS =(building information model* AND BIM*)	Original research articles, reviews, and conference proceedings with the keywords included in the Title, Abstract, and/or Author-Specified Keywords.
Li et al. (2017) Expanded Dataset	1,874	2004-2015	Core Dataset + WoS citation report links	TS =(building information model* AND BIM*)	Original research articles, reviews, and conference proceedings with the keywords included in the Title, Abstract, and/or Author-Specified Keywords.
Santos et al. (2017)	381	2006-2015	Web of Science (WoS) + Journal Databases	1 = TS = ("BIM") and ("Building Information Modelling") and ("Building Information Modeling") and ("Building Information Model")	1 = Phrase is included in Title, Abstract, and/or Author-Specified Keywords (980 papers) 2 = Phrase is included in full text (89 papers) 94 duplicates found and removed.
Zhao (2017)	614	2005-2016	Web of Science (WoS)	TS =(building information model* AND BIM*)	Original research articles only
Hosseini et al. (2018)	2,444	2003-2016	Scopus	("building information modelling") and ("building information modeling")	No publication type specified. Grey literature included.

[a] "*" denotes a fuzzy search. "TS" is WoS notation for "Topic" which limits search results to Title, Abstract, and/or Author-Specified Keywords.
[b] Capitalised Boolean terms are included in the search string e.g. "AND". Uncapitalised terms between parentheses indicate separate search strings e.g. "() and ()".

Table 2.4 Data analysis methods for existing bibliometric studies

	Study	"Themes"	Software	Analysis Method
	Yalcinkaya and Singh (2015)	Principle Research Areas	Rapidminer 5.0	**Latent Semantic Analysis** using: • Text mining (text occurences and reduction) • Calculating Factor-Solutions • Cross-Factor Analysis
Li et al. (2017)	Core Dataset	Knowledge Domains	CiteSpace (*version unspecified*)	**Network Analysis** using: • Keyword Co-Occurrence Analysis • Document Co-Citation Anaylsis
	Expanded Dataset	N/A	CiteSpace (*version unspecified*)	**Citation Burst Analysis** (*not used for identifying knowledge domains*)
	Santos et al. (2017)	Categories and Sub-Categories	N/A	**Grounded Approach** using: • Content Analysis (21 review articles were excluded for this 360 papers were used) • Tested for reliability using Cohen's Kappa
	Zhao (2017)	Research Clusters	CiteSpace 5.0	**Grounded Approach** using: • Co-Authorship Analysis • Co-Citation Analysis (with Cluster and Citation Burst Analyses) • Co-Word Analysis
	Hosseini et al. (2018)	Research Clusters	VOSviewer, CiteSpace, and Gephi	**Network Analysis** using: • Document Co-Citation Analysis • Citation Burst Analysis • Direct Citation Analysis of Outlets (e.g. specific journals) • Co-Authorship Analysis

Replicating the data collection method employed by Zhao (2017) a simple keyword search in the Web of Science (WoS) core collection database provides an updated synopsis of journal article outputs over the past 15 years – see Figure 2.2 for a snapshot of the method, search parameters, and outcomes.

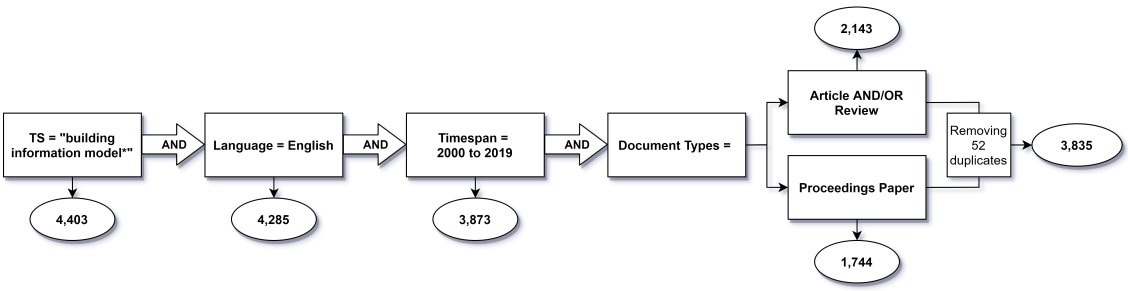


Figure 2.2 Replicated bibliometric method and results, adapted from Zhao (2017). Data from Web of Science (2020).

Whilst the WoS database does not provide an exhaustive list of publications, it does provide an indicative historical trend of BIM as a research domain. Demonstrating these data longitudinally, Figure 2.3 presents the article outputs up to the year 2019 inclusive. The findings substantiate and update those of Zhao and further supports BIM's increasing relevance in current research practices. For instance, the data provided demonstrates approximately 76% of articles have been published between 2015 and 2018 inclusively, which only represents the last quarter of the period under review.

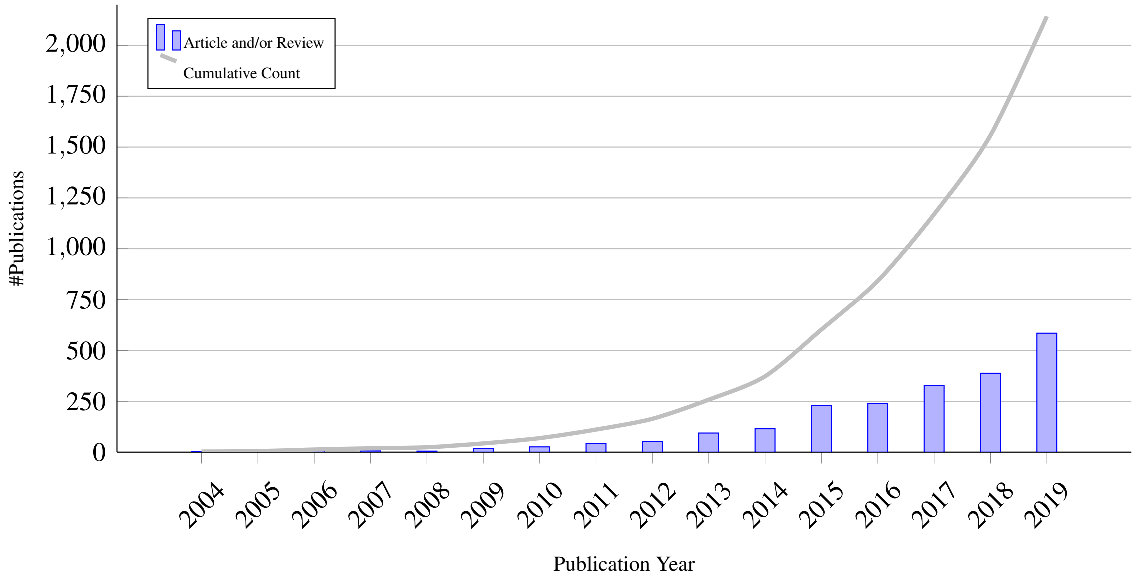


Figure 2.3 Number of BIM publications over time for the period 2003 to 2019 inclusively by year. Data from Web of Science (2020).

Work by Hosseini et al. (2018), Zhao (2017) and Badrinath et al. (2016b) also demonstrate that BIM as a research topic is being embraced by countries all over the world, which aligns with global pressures for national governments to mandate BIM adoption within their AECO sectors. Studies published by the Construction IT Alliance (Mcauley, Hore, and West, 2017) and the Scottish Futures Trust (2016) substantiate this claim by illustrating a surge in pan-continental governmental mandates in 2016 and 2017.

Research grounded within statistical bibliometrics enables researchers to minimise bias which may arise from any subjective interpretation of the results (Hosseini et al., 2018). In addition, quantitative literature-based methodologies can be generalised for repeating the analysis periodically to assess change in these trends and in the wider domain (e.g. see the recommendations of Li et al. (2017) and Yalcinkaya and Singh (2015). By utilising hard data to ascertain the landscape of BIM research, we can start to develop an understanding of the current state of BIM knowledge through the identification of themes, trends, and patterns (Yalcinkaya and Singh, 2015; Zhao, 2017). By doing so, future research efforts can be appropriately positioned by framing methodological decisions within the context of this rapidly developing research environment.

This is evidenced by Santos et al. (2017) who found that, despite an exponential growth of the domain over a relatively short time span, studies have generally matured from early conceptual, explorative work into more complex applications. This is likely occurring as BIM is being embedded into regular practice which has allowed researchers to access actual project data on which to build reliable evidence bases for their studies. In addition, as BIM matures, its tools and processes will likely adapt and grow as we move onto the next generation of digital technologies. This again is supported by the findings of Santos et al. (2017) and backed up by Zhao (2017) who both highlighted advanced technologies such as cloud computing, laser scanning, and augmented reality to be "hot topics" due to the attention these areas have received recently.

Hosseini et al. (2018) however criticise the current body of knowledge surrounding BIM, believing it to be "for the most part, fragmented and adrift" (2018, p.10). The authors instead advocate the use of *research clusters*, as identified through bibliometrics, to structure the extant corpus from which gaps in knowledge can be identified from a holistic perspective. The use of "clusters", or categorisation of themes based on converging citation networks and findings, is not necessarily novel to this work. Interestingly, although each study applied different data collection and statistical analysis techniques, Table 2.5demonstrates a broad alignment between the emergent themes of the individual studies. Whilst not surprising given the focus on one specific research domain, the aggregation of these results provides the underlying knowledge structures with further assurance and validity.

Table 2.5 Alignment between the emergent themes

"Categories"	**Santos et al. (2017)** "Sub-Categories"	**Yalcinkaya & Singh (2015)** "Principle Research Areas"	**Li et al. (2017)** "Knowledge Domains"	**Hosseini et al. (2018)** "Research Clusters"
Collaboration Environments and Interoperability	Interoperability and IFC	Information Exchange and Interoperability	Building Information; Rich Semantic Information, Industry Foundation Classes (IFC)	Collaboration
	Semantic BIM and Ontology			
	Collaborative Environments		Architectural Design Studio; Design; Collaborative Working	
	Knowledge and Information Management	Architectural Design Process		
Sustainable Construction	Energy Performance and Simulation	Energy Performance and Simulation		Green Building
	Sustainable Performance			
	Building Performance			
BIM Adoption and Standardisation	BIM Adoption	Implementation and Adoption	Different Discipline; BIM Adoption and Implementation	
	BIM Training and Education	Academy and Industry Training	CEM Curriculum; Learning Effect; Pedagogy	Education
	Rule Checking and Standards	Design Codes and Code Compliance		
	BIM Benefits and ROI	Promotion and Technology Development		
Image Processing, Laser Scanning, and Augmented Reality	AR-Based Framework/Application		Augmented Reality; Defect; Information Retrieval and Visualisation	Augmented Reality
	Image Processing			Visualisation
	Laser Scanning			
BIM Programming	Parametric Modelling		Point Cloud; Automated 3D Modelling; As-Built Data Collection and Modelling	
	BIM Tool Development			
	Cloud Computing			
		As-Is, As-Built Data		
Facilities Management and Safety Analysis	Building Management and Maintenance	Maintaining and Managing Facilities	Existing Building; Facility Management; Sustainability	
	Safety Management	Safety Management		Safety
BIM and Spatial Information	Geographical Information System (GIS)	Urban/Building Space Design and Analysis	Unified Building Model, 3D Geo-Information System; Integration of BIM and GIS	
	Space Syntax			
Construction Management	Schedule Management	Construction and Project Management	Lean Construction	Lean Construction
	Quantity Take-Off		Multi-Standpoint Framework; Stakeholder; Decision-Making	Project Management

Hosseini et al. (2018) challenged these previous bibliometric studies for their failure in drawing any substantive meaning from their datasets. The authors argue that these static, summative descriptions fail to diagnose concerns and opportunities for future investigations. For example, they found the research clusters to be "self-referential" and to very seldom draw on theoretical insights from other disciplines. Hosseini et al. (2018) then use these findings to prescribe a series of recommendations for future BIM research, highlighting the value of focused scholarly debate which borrows related concepts from other domains. Moreover, the authors caution against creating niche, splintered studies which fall outside these defined clusters and stress the advantages of achieving a mature, collaborative research environment.

Such prescriptions give rise to the need to develop a specialised ontology[2]. This would enable the extant domain knowledge to be analysed and organised according to specialised taxonomies which in turn enables a common vocabulary and understanding among researchers (Noy and Mcguinness, 2002; Turk, 2006). The need for such a facility can be exemplified through how the research clusters have been named across the studies presented in Table 2.4.

Within the BIM domain, this has been pioneered by Succar (2009) who has developed a comprehensive BIM Ontology which sits within a wider BIM Framework. Succar's BIM Framework is a "research and delivery foundation that maps domain dynamics and allows AECO stakeholders to understand underlying knowledge structures and negotiate BIM implementation requirements" (Succar, 2009, p.359). In practical terms, the BIM Framework provides a series of conceptual tools and models which can be used by academic scholars and industry practitioners to design and deliver research according to their needs. To achieve accessibility across this varied audience, the BIM Ontology uses a common language schema comprised of four high-level knowledge objects: concepts, attributes, relations, and knowledge sets. These are described in Table 2.6.

[2]The word *ontology* is borrowed from philosophy (see Chapter THREE for further discussion and philosophical application). The term is used here to denote *scientific ontology*; that is, understanding and systematically mapping "what exists" for a discipline. See the work of Gruber (1993), as cited in Turk (2006) and Succar (2009) for its definition as used within the computer science domain.

Table 2.6 Succar's BIM Ontology and associated knowledge objects. Adapted from Succar (2015).

Objects	Description	Examples
Concepts	A mental construct	Component, Document, Role, Model, Product, Responsibility, Equipment,etc.
Attributes	Values and qualifiers associated with **Concepts**	Cost; Count; Description; Location; etc.
Relations	Connections between **Concepts,** i.e.the effect of one Concept on another	Approves; Detects; Supplies; Transfer; Validate; etc.
Sets [a]	A purposeful compilation of **Concepts**, their **Attributes** and **Relations**	→ Knowledge Foundations *(e.g. BIM Ontology)* → Knowledge Blocks *(e.g. a dictionary item)* → Knowledge Tools *(e.g. a specific piece of software)* → Knowledge Workflows *(e.g. a construction method)* → Knowledge Views *(a method of self-contained knowledge dissemination e.g. journal article or training manual)*

[a] These specific Knowledge Sets have been produced as conceptual tools to be used as part of the BIM Framework. Whilst not described within his initial article, Succar's BIMe Initiative portal contains his extensive catalogue of work (www.bimframework.info).

Succar's work has unsurprisingly attracted significant attention. For example, citation analyses conducted by Zhao (2017) and Li et al. (2017) demonstrate a high frequency of citations of Succar's seminal work, with both papers identifying it as the most frequently cited journal article in the domain. Nevertheless, as a broad, conceptual study, it remains unclear as to what extent researchers have embraced the BIM Ontology, if at all. To this end, citation analyses are insufficient as a metric to understand how influential a study can be in application. This is a concern, as the need for a specialised ontology has only intensified since the initial publication of Succar's BIM Framework in 2009, given the extraordinarily high volume of BIM publications since (see Figure 2.3) and the increase in BIM coverage in general.

2.1.3 Key Terms and Concepts

To promote the school of thought surrounding a unified ontology, the key terms and concepts should be delineated within the context of the present study to provide a consistent point of reference. This is because the need for a common lexicon within such an ontology further increases as researchers begin to observe the recommendations to draw from other disciplines as suggested by Hosseini et al. (2018). This is evidenced by Ahmed and Kassem (2018), who contend that the terminology surrounding the topic of *BIM Adoption* is disjointedly applied across studies as scholars adopt time-tested theories and constructs from other domains, such as Information Systems (IS) research.

To overcome these issues and to provide cohesion to the topic, Ahmed and Kassem developed and validated an extensive Unified BIM Adoption Taxonomy (UBAT). Whilst not a holistic ontology for wider BIM research, the UBAT exists to synthesise relevant concepts from extant work, including broader innovation adoption studies, and stratify them according to a classification hierarchy (Turk, 2006). Ahmed and Kassem label these stratified classifications as drivers, factors, and determinants – see Figure 2.4 for a diagrammatic representation. This places the research topic of BIM Adoption as one of the more established areas for producing relevant, contextualised studies which are pertinent to the recommendations of Hosseini et al. (2018) and the earlier works of Succar (2009).

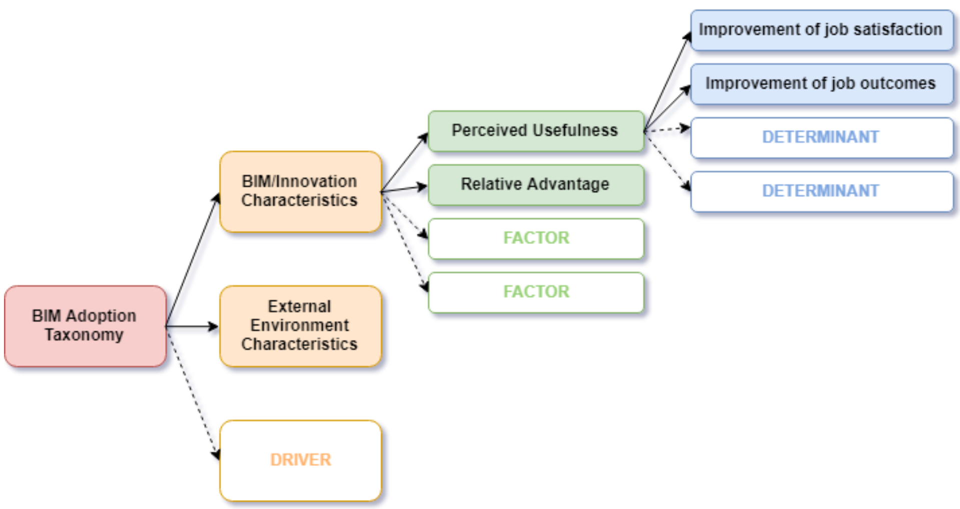


Figure 2.4 Unified BIM Adoption Taxonomy, adapted from Ahmed and Kassem (2018).

In addition to identifying and subsequently classifying a disparate catalogue of constructs, Ahmed and Kassem (2018) identified a further symptom of deriving theory from neighbouring research domains concerning innovation adoption: key terms guiding the research, such as *adoption*, *implementation*, and *diffusion*, are often applied interchangeably across studies. The authors posit that there has been little universally accepted distinction made between these seemingly etymologically related concepts, even in wider adoption research. However, as a novel innovation to a sector with a substantial research domain, an opportunity exists to harmonise the terminology surrounding BIM adoption specifically. For example, Succar and Kassem defined and substantiated the interactions between the key terms by embracing the connotations each has pertaining to the scale of investigation. This scale is described as a Knowledge Concept within the BIM Framework as the Organisational Scale (see Table 2.7).

Table 2.7 Granularity of organisational scales of innovation adoption, adapted from Succar (2012)

Low Detail			**High Detail**	
Name [1]	**Name** [2]	**Granularity**	**Name** [1]	**Granularity**
Macro	Market	Markets (M)	Macro M	Market
			Meso M	Defined Market
			Micro M	Sub-Market
		Industries (I)	Macro I	Industry
			Meso I	Sector
			Micro I	Discipline
				Speciality
Meso	Inter-Organisational	Project Teams	N/A	Project Team
Micro	Intra-Organisational	Organisations (O)	Macro O	Organisation
			Meso O	Organisational Unit
				Organisational Team
			Micro O	Organisational Member

[1] According to Succar (2012)
[2] According to Papadonikolaki (2018)

By doing so, the successful adoption by an individual unit at the micro-level – i.e. the implementation of an innovation – is differentiated from the successful spread through a population at the macro-level – i.e. the diffusion of an innovation. Moreover, the term *adoption* is proposed to overlay both, representing a more holistic term which encompasses the nuances contained within each. This broadly aligns with the observations of Papadonikolaki (2018), who differentiates the macro and micro views of BIM adoption according to whether studies are conducted at the market and intra-organisational levels respectively. Hailing back to the early work of Succar et al. (2012) as presented in Table 2.7, Papadonikolaki also considers the intermediate meso perspective which relates to activities conducted at the project or inter-organisational level. Unlike Succar and Kassem (2015), Papadonikolaki argues that implementation is more appropriately applied to a meso context and instead relates adoption to the process undertaken by isolated individual units.

However, with regards to the use of language, the differentiation between adoption at the micro- and the meso-level is negligible. A typical construction project involves a myriad of roles and responsibilities which will also correspond to varying levels of BIM implementation by each, thus bringing the focus back to the adoption by the individual. In addition, the process of individual adoption would be interwoven with implementation which can only be conducted in a live project environment. With these considerations in mind, the terminology used in the present study focuses on the individual at the micro-level and groups at the meso-level.

Although conceptualised as tools for understanding BIM adoption specifically, this terminology is reminiscent of that coined by Rogers (2003), as presented in Table 2.8. Rogers pioneered our cognisance of innovation adoption through his seminal work which was first published in 1962 and is still abundantly used to frame studies investigating today's modern innovations. This legitimises the efficacy of the terms used to describe BIM adoption by drawing on robust academic theory and contextualising it within the wider BIM Ontology. By building on these firm foundations, the present study will contribute to the wider discussion surrounding the establishment of a robust taxonomy for BIM and for wider innovation adoption research.

Table 2.8 Comparison of key adoption-related terms and their definitions

Term	Definition (Rogers, 2003)	Definition (Kassem and Succar, 2017)
Adoption	A decision to make full use of an innovation as the best course of action available.	A single construct combining the concepts of implementation and diffusion.
Implementation	Implementation occurs when an individual (or other decision-making unit) puts an innovation into use.	The set of activities undertaken to prepare for, deploy or improve specific deliverables (products) and their related workflows (processes).
Diffusion	The process by which an innovation is communicated through certain channels over time among the members of a social system.	A concept that represents the spread of the system/process within a population of adopters.

2.1.4 BIM as a Construction Innovation

Research on innovation adoption is conducted in a vast arena covering many subject areas and using a large variety of approaches from many different perspectives (Damanpour and Schneider, 2006). This relative ambiguity is captured in the widely-accepted definition of the term *innovation*: innovations can be ideas, practices, or objects, so long as the concept is perceived as novel by the unit of adoption, e.g. an individual, a project team, or an organisation (Rogers, 2003). As a novel concept to the AECO sector which constitutes a change in practice for the individual factions and actors within it, the positioning of BIM as an innovation therefore aligns with Rogers' definition of innovations. However, Slaughter (1998) and Hosseini et al. (2015) develop the concept further to situate innovations specifically within a construction context by recognising that a phenomenon must satisfy several core attributes to be classified as a *construction innovation*. As with Rogers's definition, these attributes concern the novelty of the innovation to the adopting body, in addition to whether non-trivial change in practice has incurred, and the envisaged advantages and risks of adopting the innovation specific to the construction context.

Appraising BIM against these attributes is somewhat trivial without contextualising its role as an innovation to be successfully adopted across a large sector. Therefore, given the interacting sociological and technological connotations of BIM, the present study looks towards the work of Chris Harty (2005). Harty advocates the use of a sociology of technology approach to understand a construction innovation by drawing on two intersecting ideas. The first considers the social contexts in which the innovation is to be situated and the second develops an understanding of the implications of introducing the innovation into these contexts.

The importance of an innovation's social contexts is outlined in Everett Rogers's seminal work, the *Diffusion of Innovations* (Rogers, 2003). Rogers posits that the structure of the social system – that is, the complete population comprised of units of adoption – forms one of the crucial elements which affects how and to what extent an innovation is adopted across a population. This emphasis on an innovation's social contexts have since been reiterated within a construction context by Kulatunga, Amaratunga and Haigh (2006), Widén and Hansson (2007), and Poirier, Staub-French and Forgues (2015).

However, sector characteristics, such as the social structure of an industry, are rarely considered when assuming a pan-sectoral view of issues. For example, cross-industry comparisons such as those conducted by the McKinsey Global Institute (2015; 2016; 2017) use indiscriminate metrics to enable like-for-like evaluation which do not capture the nuances or complexities of individual sectors. Although Winch (2003) attributes this to the inherent flaws in how we classify and understand our sectors[3], this translates to complicating our ability to understand how sector characteristics and its social structure can impact on how innovations are adopted across a population (Rogers, 2003; Taylor and Levitt, 2007; Widén and Hansson, 2007).

Despite this lack of attention, it has been mooted that the spread of an innovation behaves differently in a project-based industry, such as motion picture, healthcare, and construction, when compared to traditional hierarchically ordered sectors, such as manufacturing. For example, Taylor and Levitt (2004b; 2005a) suggest innovations spread more slowly through project-based industries as a symptom of the inter-organisational networks on which they are built. This effect is particularly prevalent in complex systems such as the AECO sector which requires the constant creation of temporary alliances comprised of

[3] See footnote 1 in Chapter ONE.

short-term, inter-organisational relationships (Slaughter, 1998; Harty, 2005; Widén and Hansson, 2007).

These relationships also shift and adapt as the project progresses through design, construction, and into operation and maintenance stages, leading to construction projects being considered as complex systems in themselves (Hosseini et al., 2015). In addition, as each project is generally bespoke in both its design nad the project team configuration, work typically assumes a short-term economic perspective which restricts scope for long-term investment in innovations (Widén and Hansson, 2007; Farmer, 2016). When also considering the limited dialogue between project teams and clients post-handover, these factors result in fuzzy knowledge boundaries, chaotic knowledge flows, and ill-defined feedback loops, which can hinder the rate of innovation spread within a complex social system such as the AECO sector.

The second consideration advocated by Harty is that an innovation's success also depends on the mode of innovation being considered (Harty, 2005). The mode does not necessarily differentiate or categorise innovations based on their inherent characteristics, but rather its influence on the context into which it is being introduced. Descriptors for specifically construction innovation modes stem from the work of Slaughter (1998) who acknowledges the unique conditions of the AECO sector and its projects when compared to traditional management and economic theories of innovations. Slaughter presents a scale for construction innovation which spans from innovations which require organisations to undergo small process changes to innovations which demand major changes in their current practices and links with other systems. Tayler and Levitt (2004, 2005, 2005a) and Harty (2005) refine the scale and introduce two broad innovation types:

1. **Incremental** or **bounded** innovations, which describe those "that reinforce the existing product or process and provide a measurable impact on productivity" (Taylor and Levitt, 2004b, p.5) and with implications that do not reach beyond a "single, coherent sphere of influence" (Harty, 2005, p.512), and,

2. **Systemic** or **unbounded** innovations, which describe those which "require multiple

> firms to change their processes" (Taylor and Levitt, 2004b, p.2) and "requires knowledge integration by the network of firms assembled to complete the project" (Alin et al., 2013, p.98).

Incremental innovations are considered relatively simple for actors to adopt, given their propensity to build upon current knowledge and reinforce existing practices (Slaughter, 1998; Lindgren, 2016). As an example, Harty (2005) uses 2D-CAD to demonstrate the application of what he terms as bounded innovations in the construction context. Although drafters required considerable changes in their workflows when 2D-CAD was introduced, the amount and type of information that was being produced remained the same. In addition, a drafter's adoption of 2D-CAD had little significance on other actors in the project. This is because the paper-based outputs would contain the same information having been produced using the same drawing conventions used when hand-producing drawings. Harty concludes this example by explaining that the decision to adopt and the resultant consequences were therefore contained within the adopting body.

On the other hand, systemic innovations are considered inherently more complex for actors to adopt, given the impacts and implications the act of adoption would have on interdependent actors, firms, and processes (Gallivan, 2001). A coordinated effort is required from all parties to alter system processes which cross professional and trade specialisations (Gallivan, 2001; Taylor and Levitt, 2005a; Hall, Algiers, and Levitt, 2018). Examples of AECO-based systemic innovations include timber-based building systems (Lindgren, 2016) and the application of 3D-CAD as a multi-disciplinary information coordination tool (Harty, 2005). The latter actually represents a precursor to the modern interpretation of BIM, which has collaborative processes enabled through 3D parametric modelling embedded at its core. To contextualise the degree of change required, Harty explains that "Full specification of designs is needed in order to construct the virtual building [...] reconfiguring the sequences in which construction work is undertaken" (Harty, 2005, p.516) and that it "extends from its actual location within CAD departments potentially to affect the coordination of the whole construction process" (Harty, 2005, p.516). Similarly, BIM requires the same shift in sequencing to enable the development of a virtual building through parametric modelling procedures.

However, collaborative modelling using 3D parametric objects forms one of many ideas in the complex, multifaceted system that comprises BIM. For example, the BS 1192:2007+A2 standard requires an agreed-upon file-naming convention to be used within a common data environment (CDE) which is shared by all parties. This ensures all information is searchable and easily understood by all granted access to the CDE. With the vast amount of information being constantly generated in any given project, the process would be inefficient and ineffective if one party was applying a different file-naming procedure, or not using the CDE at all. As a further example, Gledson applied similar logic in his doctoral work to the use of four-dimensional (4D) BIM, referring to it as a "modular technological process-based innovation" (Gledson, 2017, p.90) which sits within the wider system of BIM.

To this end, BIM is not only a systemic innovation, as supported in multiple studies such as Alin et al. (2013), Singh and Holmstrom (2015), and Papadonikolaki (2018), but also a multifaceted one comprised of several "modules" or "attributes". Reminiscent of its multi-constituent definition, BIM is therefore a multifaceted innovation in that each individual module may also be novel to the actor and may therefore also consist of its own adoption decision and diffusion process (Gholizadeh, Esmaeili, and Goodrum, 2018). Moreover, this multifaceted nature gives the innovation room to evolve and its different parts will likely have different effects on different people at different times (Shibeika and Harty, 2015).

Notwithstanding the complex nature of BIM as a multifaceted systemic innovation, its introduction to the AECO represents a significant challenge. Although Taylor and Levitt (2004a) posit that the construction industry is actually comparable to manufacturing sectors when comparing the market-level adoption behaviour of incremental innovations, the same cannot be said for systemic innovations. Several studies remark that systemic innovations fail to penetrate project-based industries, and in particular the AECO sector, as rapidly or as widely as its counterpart (Lindgren, 2016; Hall, Algiers, and Levitt, 2018). However, if the conditions are right, systemic innovations can diffuse in project-based environments. Taylor and Levitt (2005b) propose that the success of systemic innovation diffusion requires:

- **Strong relational stability**, which describes the degree of organisational variety in the constituency of the project team from project to project,
- **Network-level interests**, which describes how invested industry actors are in the wider sector rather than focusing solely on internal interests,
- **Fluid boundary strength**, in which work could be redistributed amongst project team members to accommodate process changes stemming from introducing an innovation, and,
- The existence of an **agent for network-level change**, which describes a body that advocates and supports the introduction of an innovation.

Whilst the traditional structure of the AECO sector does not accommodate nor generally support these requirements, BIM is acting as a catalyst for change and pockets of industry are starting to embark on a more collaborative journey towards the model proposed here. To further stimulate this significant shift in the sector's sociological contexts to reach the wider industry, actors need to become more aligned in their inter-organisational practices and in their adoption of BIM as a systemic innovation (Alin et al., 2013). In such a complex, multidisciplinary environment, this can only be realistically achieved through effective, coordinated governance and central support (Lindgren, 2016).

2.2 BIM Adoption at the Macro-Level

As outlined in Chapter ONE, the adoption of BIM is predicated on the purported benefits realised through embracing digital and collaborative processes. However, to realise these efficiency gains at a sector-wide scale, the BIM discourse needs to be effectively communicated and diffused throughout industry. Yet as the departure point of the previous section established, BIM's role as a systemic innovation within an inherently complex sector presents a significant challenge. This section therefore reflects on the mechanisms being used to drive BIM adoption in the UK and provides context to its journey in relation to the wider digitisation discourse currently being expressed worldwide.

2.2.1 Diffusion Mechanisms and Change Agents

With amounting pressures growing for national governments and their AECO sectors to implement BIM, extant literature is demonstrating a global interest in understanding why, how, and to what extent BIM is diffusing within countries and across continents (e.g. Wong, Wong, and Nadeem, 2009; Smith, 2014; Cheng and Lu, 2015; Hooper, 2015; Jung and Lee, 2015; Succar and Kassem, 2015; Gerges et al., 2017; Kassem and Succar, 2017; Li et al., 2017; Yang and Chou, 2018; Charef et al., 2019; Ahuja et al., 2020; Troiani et al., 2020, etc.). To do so, many studies draw on classic innovation diffusion theory as popularised by Everett Rogers (2003). The premise of innovation diffusion theory is that adoption by individual actors will influence others within the social system in which they are embedded, thus causing a cumulative diffusion effect. When mapped numerically against time, this typically translates into an S-shaped curve – as illustrated in Figure 2.5 – which has been continuously validated in diffusion studies over many different, diverse disciplines.

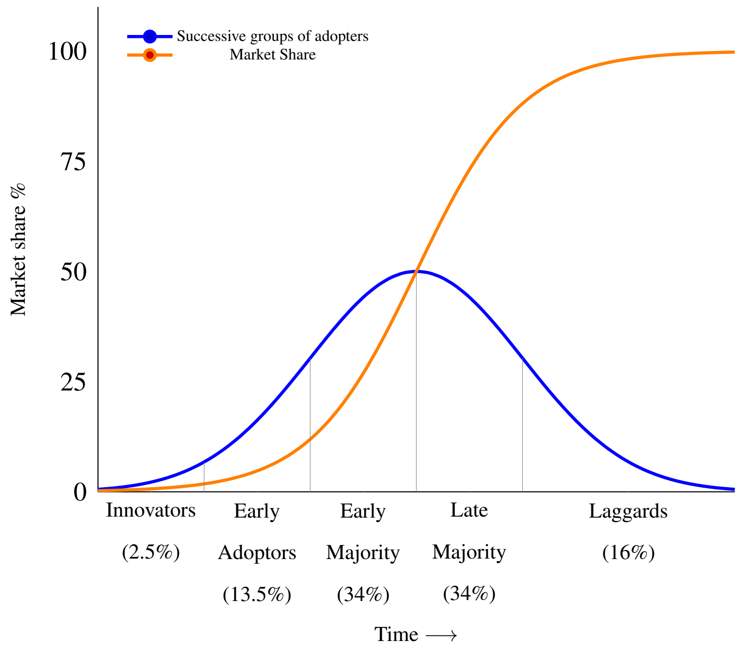


Figure 2.5 Typical pattern of innovation diffusion, adapted from Rogers (2003)

Rogers (2003) defines this process as the rate of adoption. He explains that the rate of adoption is determined by several factors, including the perceived attributes of the innovation, the type of innovation-decision being employed by the unit of adoption, the nature of the social system in which the innovation is to be embedded, and the extent of a change agents' promotion effects. As the previous section stated, a body promoting network-level change, or a *change agency*, is one of the factors which influences the successful diffusion of a systemic innovation.

One of the concepts bridging the change agency and the units of adoption is the change agent role. The change agent is described by Rogers (2003) as an actor capable of stimulating innovation adoption behaviour across other actors to support wider diffusion. In classic diffusion studies which consider diffusion to be a linear, top-down driven approach, the change actor facilitates the communication stream directly between the change agency and the individuals. However, Rogers acknowledged the emergence of non-linear, decentralised diffusion patterns which did not rely on a separate change agent driven at the network-level, but was instead generated and spread at the operational levels of the social system. In such situations, diffusion occurred horizontally between bodies and peer networks in a bottom-out function, rendering the adopters their own change agents.

Succar and Kassem (2015) develop these observations to sit within the BIM context. As a Knowledge Concept within Succar's BIM Framework (see Table 2.6), the scholars conceptualised a Macro-Diffusion Dynamics model to understand the diffusion mechanisms being applied at a national level; that is, mapping from where and how BIM diffusion starts to unfold across the social system or network. Building on the observations of Rogers who begun to identify vertical (centralised) and horizontal (decentralised) pressures in diffusion networks, the model proposes three core diffusion dynamics: top-down, middle-out, and bottom-up. It is suggested that the adoption decisions of one actor, which in this instance would be the change agent, will exert a form of isomorphic pressure on others within the network to adopt BIM (Cao, Li, and Wang, 2014b). The type of pressure and in which direction it is exerted is predicated on where in the model the change agent sits, i.e. whether the pressure is of a coercive, mimetic, or normative nature (DiMaggio and Powell, 1983;

Scott, 2014).

Within the UK, the adoption of a BIM approach within the political agenda in the UK stemmed from the Government Construction Strategy (GCS) 2011-15. By stipulating a mandate, HMGov exerted a so-called 'push-pull' strategy: the Government provided the impetus for BIM adoption by requiring it on public-sector projects, and the supply-side would develop and deliver information to the stipulated standard. Moreover, a central approach is pivotal in creating appropriate levels of support and standardisation for industry to be able to 'pull'. This is because in addition to the role of initiator/driver, the public-sector can also play the role of regulator, educator, funding agency, demonstrator, and/or researcher in stimulating BIM use (Cheng and Lu, 2015). According to Troiani et al. (2020), greater public-sector client engagement with these roles will lead to more of the supply side of industry accepting BIM and effective diffusion can occur.

By enforcing the BIM adoption mandate, the UK is one of three countries, including Hong Kong and the United Arab Emirates, employing a predominantly top-down diffusion dynamic (Kassem and Succar, 2017). This means that governmental pressures, and by extension client demand, are considered a driver for BIM adoption by industry practitioners (Wong, Wong, and Nadeem, 2009; Eadie et al., 2013b; Vass and Gustavsson, 2017; Ayinla and Adamu, 2018). However, as the mandate only concerns public-sector projects, private-sector clients do not have to adopt BIM or stipulate it as a requirement for their supply chain. Therefore, the mandate cannot be considered to be industry-wide.

Nevertheless, it is suggested that BIM diffusion in the UK is also being communicated via horizontal mechanisms; in lieu of being subject to coercive mechanisms, organisations who primarily work on private-sector projects may instead be influenced by the mimetic effects from peer organisations or through normative pressures from within their own supply chain. To this end, the adoption of BIM in the UK can be said to be operating in a quasi-centralised diffusion system in that the governmental mandate is enforcing BIM engagement within the government's own supply chain, but is relying on peer diffusion elsewhere (Rogers, 2003).

Yet, Porwal and Hewage state that the "maturity and adoption of BIM depends mainly on the client or owner in construction projects" (Porwal and Hewage, 2013, p.204). This aligns with Won et al. (2013) who identified client requirements as one of the critical success factors for the successful adoption of BIM at an organisational level. This was again confirmed by Cao et al. (2014a) who found client/owner support to fully mediate the relationship between external pressures and the extent of BIM adoption, recommending that government agencies should work with clients to effectively exert their influence on how industry adopts BIM. However, Papadonikolaki (2018) cautions against adopting BIM purely to achieve compliance with external demand, suggesting instead that internal drivers, such as adopting BIM to increase the quality of project deliverables, should be prioritised when considering adoption at the meso-level.

Nevertheless, the lack of client demand has consistently been shown to be one the biggest barriers to BIM adoption (e.g. Eadie et al., 2013a; Almuntaser, Sanni-Anibire, and Hassanain, 2018; Ayinla and Adamu, 2018; Dakhil, Underwood, and Shawi, 2019; NBS, 2020). This is despite the client being identified as the largest beneficiary of BIM adoption (Olofsson, Lee, and Eastman, 2008; Li et al., 2017; Husain, Razali, and Eni, 2018). Moreover, as actors who have the power to influence and achieve inter-organisational change through a project setting, clients can be viewed as the change agents (Lindblad, 2019a). As noted by Linderoth, clients are "always in the ultimate position to require compulsory use of BIM" (Linderoth, 2010, p.7). Therefore, without client support from within both the public- and private-sectors, full industry diffusion of BIM may be difficult to achieve.

The shift from independently-led recommendations, such as those by Egan (1998) and Latham (1994), to governmental mandates undoubtedly represents a more driven approach to achieving widespread innovation adoption. However, this central approach to diffusion is not without criticism; a risk of non-uniform adoption exists which is favourably weighted to larger organisations and those who regularly take on public-sector projects. Yet, without empirical evidence, it is difficult to validate whether such patterns are indeed occurring and if so where to focus remedial action and resource. However, the emergence of widescale internet access has enabled digital data mining and analytics to become more accessible, thereby presenting an opportunity to measure, monitor and assess wide-scale adoption rates which has otherwise been lacking in previous industry reform attempts.

2.2.2 Measuring Macro-Adoption

There is generally an absence of academic-led, evidence-based research when considering the measurement of BIM adoption at the macro-level (Kassem, Succar, and Dawood, 2013). Perhaps the most advanced example in this area is the series of macro-adoption models developed by Succar and Kassem (2015), which is derived from the knowledge structures proposed by Succar's BIM Framework (see Section 2.1.2). Succar and Kassem framed their macro-adoption study around a series of five conceptual models focusing on diffusion areas, maturity components, diffusion dynamics (as discussed in Section 2.2.1), policy actions, and diffusion responsibilities. In an accompanying paper, the authors applied these models to present a comparative market analysis to demonstrate how different nations are approaching BIM by applying each conceptual structure as a lens through which to study their diffusion activities. This work has since stemmed into an ongoing *Macro Adoption Project* piece which "aims to assist policy makers in developing and/or assessing the macro BIM diffusion policies, strategies and plans within their respective markets" (BIMe Initiative, 2020b, para.1). Regions addressed within the project thus far include Canada, Brazil, Egypt, Ireland, Peru, and Spain.

Whilst a useful asset to inform governance in regions which are in the early stages of embracing BIM at a policy-level, actual diffusion efficacy is currently neglected by the Succar and Kassem model. Moreover, other academic studies employing a macro-perspective also either restrict their focus to comparing country-level approaches and strategies (e.g. Wong, Wong, and Nadeem, 2010; Smith, 2014) or employ a descriptive approach which do not elicit enough responses to be considered generalisable to an industry scale (e.g. Gerges et al., 2017). Another emerging theme in macro-level studies is focused on gaining a deeper understanding of contextual factors within individual countries and regions.

This gap is presently being bridged by a plethora of industry-based, commercial reports and surveys. As highlighted by Loyola and López (2018), these studies predominantly take the form of questionnaire surveys and can enjoy large sample sizes of up to 1,500 industry-based respondents. This is likely because such commercially-driven surveys benefit from heightened exposure when branded with a recognised, generally trusted name. However, Succar and Kassem (2015) outlined a series of shortcomings suffered by these survey types, such as the general neglect of the non-software aspects of BIM (i.e. not considering it as a modular innovation), the lack of transparency surrounding methodological considerations (e.g. which sampling and data collection methods have been employed), and the apparent disregard for applying an existing, or even novel, theoretical perspective.

Whilst not methodologically rigorous and oftentimes without theoretical grounding, such surveys can provide indicative adoption rates from a longitudinal perspective, as well as providing an adequate departure point for academic research to build upon. Within the UK, several such commercial-based surveys exist, such as those conducted by construction-related media outlets, e.g. BIM+ Magazine (Chevin, 2020) and McGraw Hill Construction (McGraw Hill Construction, 2014). However, perhaps the most industry-renowned study has been conducted annually since 2011 by the National Building Specification (NBS) and the results published within their National BIM Reports (NBS, 2020). The reports are self-badged as the *definitive industry update*, demonstrating their perceived status within industry.

Although the NBS National Surveys do not depict an accurate picture of all practices in the UK, they present a good representation of current standings and is the most comprehensive survey available given its broad reach across the different disciplines and sectors. Despite being based on the use of percentages rather than absolute data, the apparent standardised methodology underpinning the surveys positions the reports as useful tools to longitudinally assess indicative adoption rates. When these data are plotted against time, the trend of adoption illustrates an overall positive growth as illustrated in Figure 2.6. The 2020 National BIM Report illustrated that 73% of industry is perceived to have adopted BIM, which is an increase of 4% on 2019 figures and an increase of 60% since the first report was published (NBS, 2020). These figures seemingly corroborate the ambitions

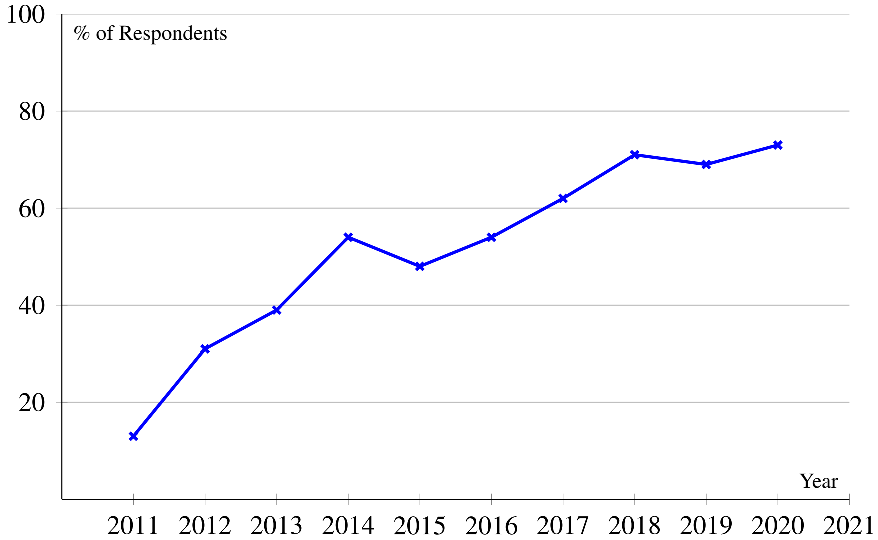


Figure 2.6 Annual BIM adoption report statistics. Data from (NBS, 2020).

of the UK BIM Alliance (UKBIMA) who set a target of 75% adoption within the supply chain by 2020 (UK BIM Alliance, 2016).

The NBS National Surveys also consider industry intent to adopt BIM. This has typically been assessed using questions targeting those who have adopted BIM and those who have yet to on their anticipated use of BIM in one, three, and five years' time. The results consistently present a cautiously optimistic outlook when considering the overall trend line trajectory, particularly in the immediate short term. However, the longitudinal perspective provided by the National BIM Reports demonstrate that these ambitions are never realised. For example, when asked in 2011 about future adoption ambitions, 94% of respondents anticipated they would be using BIM within five years. Yet, in 2016, adoption levels were 54%. Likewise, consultation of the 2016 edition indicated that 95% would be using BIM by 2019, whereas 2019 figures illustrate a different reality of 69% (NBS, 2016a; NBS, 2019).

The 2020 edition of the report acknowledged this gap between rhetoric and reality, highlighting that the "stated intention and what is actually achieved can be quite different" (NBS, 2020, p.23). Notably, the 2020 edition moved away from considering 'full' intent to adopt within one and three years, and instead probed the extent to which respondents will have adopted BIM in five years' time. The results showed that 72% of those who consider themselves to have not yet adopted BIM to be using it in some capacity by 2025.

Of this group, 46% intend to be using BIM on all or on a majority of projects. However, it is worth noting that a significant portion do not intend to adopt BIM (12%) or are unsure (16%), thereby indicating a persistent reticence regarding culture change within the BIM discourse. Nonetheless, within classic innovation diffusion theory, this is because the S-shaped function describing innovation diffusion rates suggests that adoption starts to slow as the innovation starts to penetrate those considered to be the late majority and even more so once the laggards start to embrace the innovation, as characterised by Rogers (2003). This suggests the reticence toward BIM is a natural by-product of the diffusion process.

However, the NBS approaches BIM adoption as a simple dichotomous activity, i.e. the unit of adoption either adopts BIM or it does not, thus counting adoption wholly and cumulatively. Notwithstanding the appraisal of BIM as a multifaceted systemic innovation in Section 2.1.4, this approach discounts the various iterations of BIM maturity as described by its Levels. For example, when the National BIM Report 2018 (2018) asked respondents which Level was the highest their organisation had achieved on a project, 1% answered Level 0 and 8% answered Level 3. If the reports can be considered to be representative of the wider industry, this suggests a significant portion do not understand the UK's BIM discourse. A further 21% answered that Level 1 was the highest Level achieved, which, as an elementary approach to BIM, does not extend into parametric modelling. Therefore, if we assume the crude position of understanding BIM to be bounded and defined as according to the standards-governed Level 2, then the apparent adoption rates as presented in Figure 2.6 begin to become deconstructed.

The approach of presenting BIM diffusion as a simple cumulative curve is therefore insufficient. As discussed in Section 2.1.4, BIM is best understood as a modular innovation which comprises several constituent elements. Each of these modules may then be subject to its own adoption process if it, in itself, can be considered novel to the decision-maker. It therefore stands to reason that these modules would each exhibit their own diffusion rates as the units of adoption build up their capability. Through the NBS reports, this can be demonstrated through the apparent adoption of the governing standards and publications which comprise the Level 2 suite in the UK. Figure 2.7 presents the longitudinal adoption rates of each standard and publication in the suite.

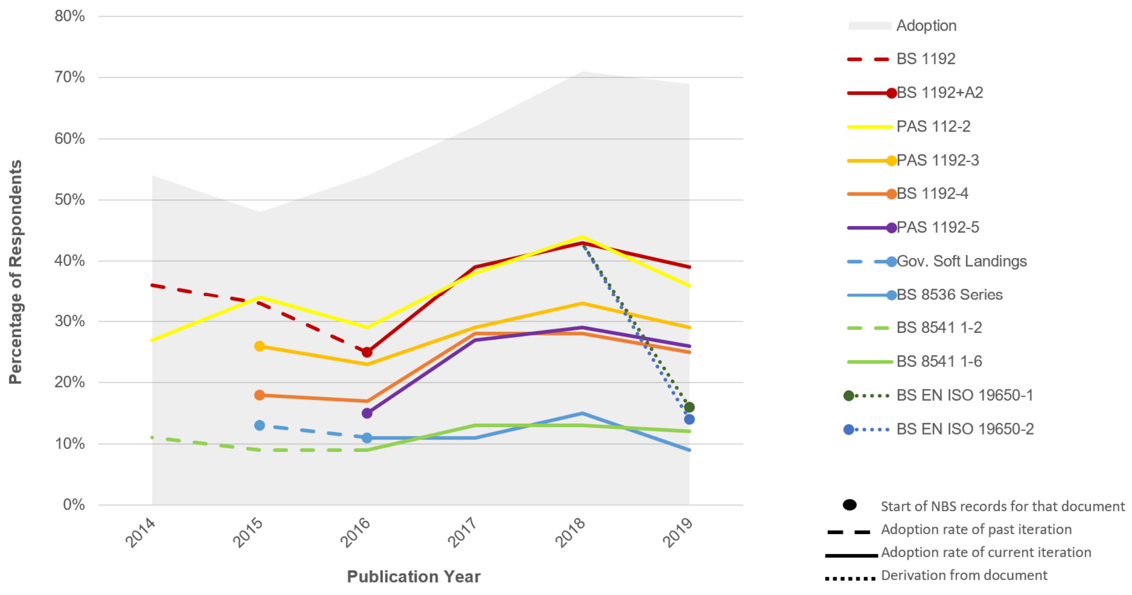


Figure 2.7 Longitudinal adoption curves of the Level 2 standards and publications. Data from NBS National BIM Reports 2011 to 2019.

As demonstrated, there are significant gaps between the overall adoption rate and those of each standard. For example, BS 1192:2007+A2 represents the most adopted standard across the whole suite and yet has only been used by 39% of respondents (NBS, 2019)[4]. Moreover, in addition to the PAS 1192-2:2013 standard, BS 1192+A2 have been superseded by the ISO standards, BS EN ISO 19650-1 and -2. Whilst similar in core principles, a shift in process and terminology will require further assimilation, threatening a further lag in realising an effective diffusion of BIM.

Whilst it could be argued that the standards only represent a single element of the wider BIM process, national-level standardisation is a critical element for successful BIM diffusion in a predominantly top-down driven adoption environment (Smith, 2014; Cheng and Lu, 2015; Hooper, 2015). Nevertheless, the data published by the NBS also demonstrates that there is a reality gap when considering how core elements of BIM are being embraced. The most prominent example lies in the apparent use of a CDE. The 2018 edition of the report highlighted that only 21% of respondents share information in a

[4] It is unclear whether the whole sample was asked about their use of standards or whether it was just those who consider themselves to have adopted BIM. The former was plotted, but if it was the latter, then all standards would exhibit even lower adoption rates (e.g. 39% of the 69% who have adopted use BS 1192:2007+A2 which represents 27% of the overall sample).

CDE on all projects, with more than half (57%) either only doing so on some projects or not at all (NBS, 2018)[5]. Yet, sharing information in a CDE is fundamental to BIM as the core principle underpinning the original BS 1192:2007 standard. Moreover, assuming the Bew-Richards definition of the BIM levels of maturity, working in a CDE forms the basis for Level 1 on which the principles of Level 2 are built.

Although the 2019 and 2020 editions did not consider the same question, similar gaps can be witnessed when considering other attributes of BIM, albeit with varying degrees of magnitude. For example, in a similar vein to CDE use in that it forms the basis of the BS 1192 standard, it was found that approximately two-thirds of respondents follow a naming convention for all shared information (NBS, 2020). The report also demonstrated mixed levels of usage when considering the suite of BIM-related documentation, e.g. 56% of respondents had involvement with exchange information requirements[6], 46% with information protocols, and as little as 32% with master information delivery plans. Furthermore, 7% of respondents indicated that they had not been involved with any of the listed documents despite having worked on a BIM project. When probed about BIM-related activities, less than half (46%) of respondents believed their organisation had adopted the use of revision codes, whilst approximately a third stated their organisation exchanges information using the COBie format.

Yet, whilst indicative, high-level evidence suggests these discrepancies between rhetoric and reality are indeed occurring, these apparent phenomena are by-products of surveys built for other purposes and therefore do not provide any further contextualised understanding. Moreover, there appears to be little work within the wider IS innovation adoption domain which indicates that such a gap surrounding systemic or modular innovations is a concern, thus providing no pre-tested tools or theoretical grounding for further investigation. Therefore, the lack of robust macro-adoption studies represents not only a dearth in empirical evidence but also a gap in understanding general diffusion effectiveness.

[5] The same caveat in interpretation, as discussed in footnote 4, applies here.

[6] Formerly known as employer's information requirements, as defined within the 1192 suite of standards.

2.2.3 Assimilation and Assimilation Gaps

Despite the apparent neglect surrounding the study of actual diffusion efficacy for systemic innovations, there are areas of study which begin to challenge how diffusion is quantified for simple, bounded innovations. For example, Fichman and Kemerer (1999) challenged the traditional Rogers model of innovation diffusion (Figure 2.5) by outlining that observed patterns of cumulative adoption can be broken down into whether the innovation is being simply acquired and whether it is actually being deployed. The authors propose that a discrepancy, or time lag, tends to exist between these two curves, which is illustrated in Figure 2.8 using the traditional S-shaped diffusion curve. By highlighting this phenomenon, Fichman and Kemerer questioned our unilateral understanding of adoption decision-making processes and highlighted the risk of subsequent over-optimistic appraisals of widespread diffusion.

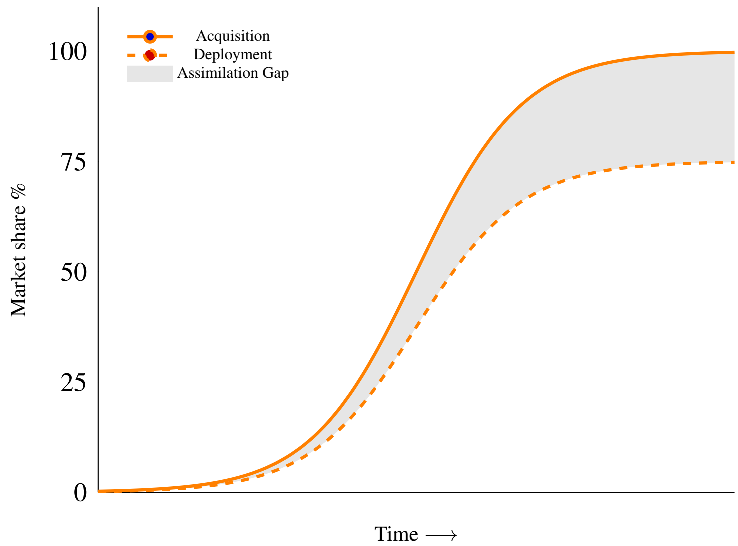


Figure 2.8 Assimilation gap between innovation acquisition and deployment, adapted from Fichman and Kemerer (1999)

By comparing Figures 2.7 and 2.8, it becomes apparent that a similar phenomenon can be seen, in that gaps exist between the perceived BIM adoption curve and the adoption trends for each of the outlined BIM standards. Although breaking away from the acquisition-deployment dichotomy and instead viewing the wider BIM adoption as a series of constituent-level adoption behaviours, the so-called illusory effect as associated with the original assimilation gap concept still persists.

Therefore, by referring to the discrepancies present between the individual diffusion curves being exhibited by each BIM module, this perspective presents a novel take on the original assimilation gap concept as defined by Fichman and Kemerer (1999). Moreover, the diffusion behaviours of each module are also likely to suffer from the acquisition-deployment discrepancy, thereby providing further depth to our comprehension of how modular innovations behave when diffusing within a population.

However, as discussed earlier, the diffusion of such innovations in project-based industries are difficult to study at the macro-level. The broader concept of assimilation can instead be considered at the meso-level, as it is interwoven into the innovation adoption decision process. For example, Fichman (2000) conceptualises assimilation as the process of transitioning from acquisition to deployment within an organisation, or achieving *full institutionalisation*. That being said, the concept of assimilation has since been expanded to encompass a broader range of adoption-related activities beyond acquisition and deployment.

For example, Gallivan (2001) develop the concept by identifying two sub-constructs of assimilation: the breadth of innovation use, i.e. the number of adopters within a bounded institution, and the depth of innovation use, i.e. the extent of use and its resulting level of impact within the institution. Furthermore, Gallivan posits that actors transition through an assimilation stage which is conceptualised using Cooper and Zmud's six-stages of IT implementation: initiation, adoption, adaptation, acceptance, routinization, and infusion (Cooper and Zmud, 1990; Gallivan, 2001). This can be viewed as an extension of the implementation stage within Rogers' innovation adoption decision process - see Figure 2.9.

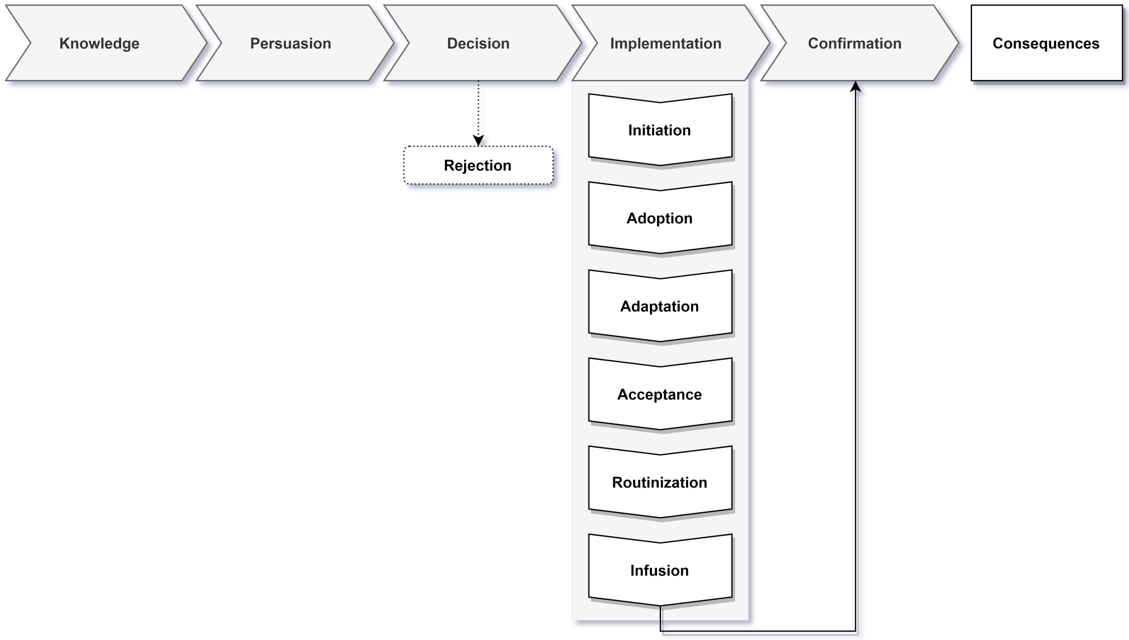


Figure 2.9 An integrated innovation adoption decision and assimilation process, adapted from Cooper and Zmud (1990), Gallivan (2001), and Rogers (2003).

By breaking down the concept of assimilation into sequential steps, the nuances that exist within the adoption of systemic, modular innovations can perhaps be better understood. For example, Bajwa et al. (2004) applied the concept of assimilation to Enterprise Resource Planning (ERP), noting that the nature of a modular innovation means that an organisation can configure its implementation according to its needs which may involve further modules being implemented at a later date. In line with this interpretation of the assimilation concept, the authors suggest the process of organisational assimilation is structured around the following stages:

- **Awareness**, which is where the decision-maker initiates the assimilation process and builds a business case for enacting change. This is akin to the 'knowledge stage' within Rogers' innovation adoption decision process (see Figure 2.9), which is defined as when the decision-maker "is exposed to an innovation's existence and gains some understanding of how it functions" (Rogers, 2003, p.162).
- **Selection**, which, in an ERP context, considers the selection of vendors and software packages.

- **Preparation**, which considers the testing of software and systems prior to implementation on a project.
- **Implementation**, which considers the practical elements of adopting the ERP systems, such as user training, detailed gap analysis, and prototype construction.
- **Operation**, which is the final stage in assimilation. This considers how the system is used, maintained, and integrated within the organisation, and includes how the organisation adapts to the changes imposed by the ERP systems.

The steps introduced by Bajwa et al. (2004) therefore start to consider how innovations are configured and assimilated based on the strategic integration with other organisational systems, particularly with regards to its technological artefacts. Moreover, the breakdown of these steps illustrates that the adoption process is complex and that effective organisational assimilation requires significant planning and resource investment. This is particularly true of systemic innovations that rely on high user interdependencies between actors and impose a knowledge burden[7] on its adopters (Gallivan, 2001).

The process of assimilation therefore complements the concept of absorptive capacity. Cohen and Levinthal (1990) define absorptive capacity as the need for an organisation to have prior related knowledge, or awareness, to successfully assimilate and use new knowledge in a productive manner. Building on the cognitive and behavioural sciences, the authors argue that the ability to assimilate this new information relies on the extent and diversity of the existing knowledge structure in place, which is in turn cultivated through the extent of investment into research and development activities.

Zahra and George (2002) expand upon this model to distinguish between potential absorptive capacities - i.e. the receptiveness of the organisation in acquiring and assimilating knowledge - and realised absorptive capacities - i.e. the function of transforming and exploiting the knowledge. Furthermore, as demonstrated in Figure 2.10, the terminology used and overall sequential structure is reflective of that used in the innovation adoption

[7] A knowledge burden is where knowledge barriers to use occur, which require extensive upskilling to overcome due to the specialised nature of the principles underlying the innovation (Gallivan, 2001).

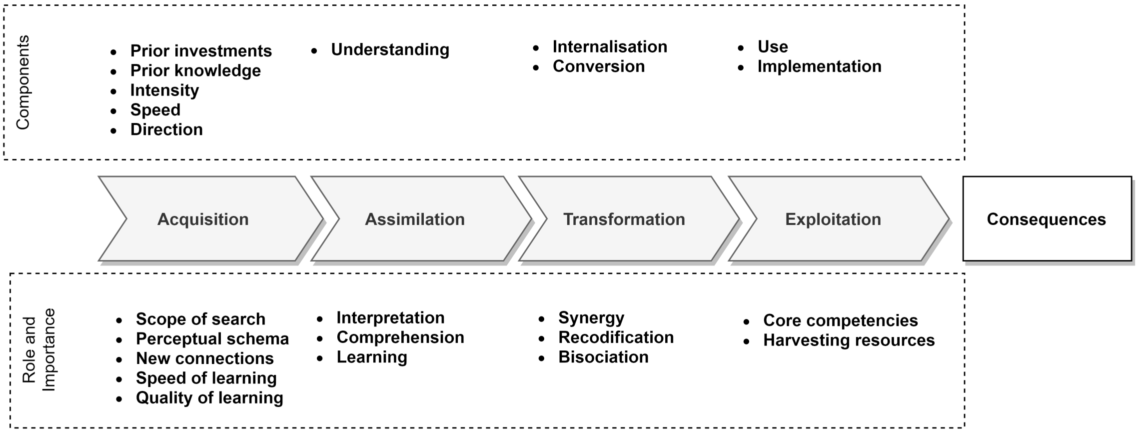


Figure 2.10 Dimensions of absorptive capacity, adapted from Zahra and George (2002).

decision process (Figure 2.9), thereby establishing a clear synergy between the concepts of assimilation within the context of innovation adoption and absorptive capacity.

2.3 BIM Maturity and Upskilling

Following the tenet presented in this chapter thus far, it can be argued that the efficacy of industry-wide BIM adoption relates to the ability of actors to assimilate it as a complex innovation. This leads onto considering the understanding and assessment of the extent of assimilation vis-*á*-vis BIM capability and maturity. This section therefore discusses extant BIM capability and maturity measures and their relationship with the concept of BIM competency and existing upskilling practices within industry.

2.3.1 BIM Capability and Maturity Metrics

When considering the quantification of an organisation's extent of BIM assimilation, the terms *BIM capability* and *BIM maturity* are frequently used. The concepts are interlinked: the former refers to "the minimum ability in performing a task or delivering a measurable outcome" (Succar and Kassem, 2015, p.175), whereas the latter refers to the "extent of BIM capabilities within organisations and project teams" (Kassem et al., 2020, p.19). Another definition of BIM maturity is offered by Chen and Cox, who state that it is "the extent to which BIM is explicitly defined, managed, integrated and optimised" (Chen and Cox, 2014, p.187). Notably, this sequential interpretation of maturity provides a framework similar to the understanding of assimilation as previously discussed.

Within a practical context, ascertaining the delivery team's capability to deliver projects using BIM is integral in establishing the lead supplier's response to the Employer's Information Requirements (EIR) by way of the pre-contract BIM Execution Plan (BEP) under PAS 1192-2 (British Standards Institution, 2013) and ISO 19650-2 (International Organization for Standardization, 2018). The compiled capability and capacity of the proposed delivery team is assessed using a supply chain capability summary form which incorporates a general BIM assessment (i.e. assessing what BIM means to the supplier and how they are implementing it), an IT assessment (i.e. quantifying the availability of relevant hardware and software), and a resource assessment (i.e. quantifying the BIM-specific experience and expertise of the staff). The compilation of this information presents an easy comparison for lead suppliers to understand where gaps may lie and to identify potential solutions via appropriate training and support prior to establishing the final BEP. The concept of BIM capability, within the context of the standards, therefore represents an organisation's capacity to deliver BIM tasks competently in relation to the client's specified requirements.

An organisation's BIM maturity, however, is better understood as a project-agnostic concept, in that it is measured and scored in relation to a standardised notion of what a 'BIM mature' organisation would be. This premise underpins the metrics of many of the so-called BIM maturity models and assessments (e.g. Chen and Cox, 2014; Succar, 2015; Liang et al., 2016; Wu et al., 2017; Siebelink, Voordijk, and Adriaanse, 2018; Mahamadu et al., 2019, etc.) and can also be extended to considering maturity benchmarking at the macro-level (e.g. Fenby-Taylor et al., 2016; Loyola and López, 2018; Siebelink, Voordijk, and Adriaanse, 2018; BIMe Initiative, 2020b; Troiani et al., 2020).

The recognition of a growing list of BIM maturity assessment tools led to a research commission by the Centre for Digital Built Britain (CDBB), in partnership with the UKBIMA, in which multiple BIM maturity and benefit assessments were evaluated by a consortium of academics and industry partners (Kassem et al., 2020). The report, published by the CDBB, identifies 15 BIM maturity tools (i.e. maturity assessments which have an interface, e.g. a web portal) and four maturity methods (i.e. maturity assessments which do not have an interface but simply provide the methodology). These included the SFT's BIM Compass (Scottish Futures Trust, 2019), the CPIx BIM assessment form (Construction Project Information Committee, 2011), the NBIMS Capability Maturity Model (McCuen, Suermann, and Krogulecki, 2012; National Institute of Building Sciences, 2020), and the BIM Excellence online platform (Succar, 2015). All identified tools were found to concern maturity at the meso-level, but varied in scope of assessment from readiness measures, compliance benchmarking, and full capability and maturity assessments.

However, the report identifies the tendency of tools to mainly rely on compliance with the BIM standards, with most tools only offering a high-level perspective of an organisation's BIM maturity. The report also identifies a wide range of varying characteristics between the tools, such as whether the tool or method is paid or free, whether the tool or method is discipline-agnostic or instead focuses on a specific discipline (e.g. contractor, procuring clients, etc.), and whether the tool considers assessments in markets outside of their originating country, i.e. whether they are market-agnostic. One of the key criticisms emerging from the report is that current metrics are ineffective, due to their reliance on self-reported assessments and use of binary (yes/no) measures. Moreover, the tools and methods are perceived to not encompass the wider supply chain beyond the design team. Despite only 28% of those surveyed indicating that they use a tool to measure their BIM maturity and the shortcomings of the current offerings, the report highlights that industry practitioners see there being a need for BIM maturity assessment.

2.3.2 Upskilling as a Facilitator of Adoption

When assessing barriers to adoption, respondents of the NBS annual surveys consistently rank competency-related barriers among the top four each year. As illustrated in Figure 2.11, these consist of lack of in-house expertise, lack of training, lack of client demand, and cost. Figure 2.11 also demonstrates only a small decrease in the percentage of respondents identifying each as a barrier to effective adoption which indicates that little has changed since the Level 2 mandates.

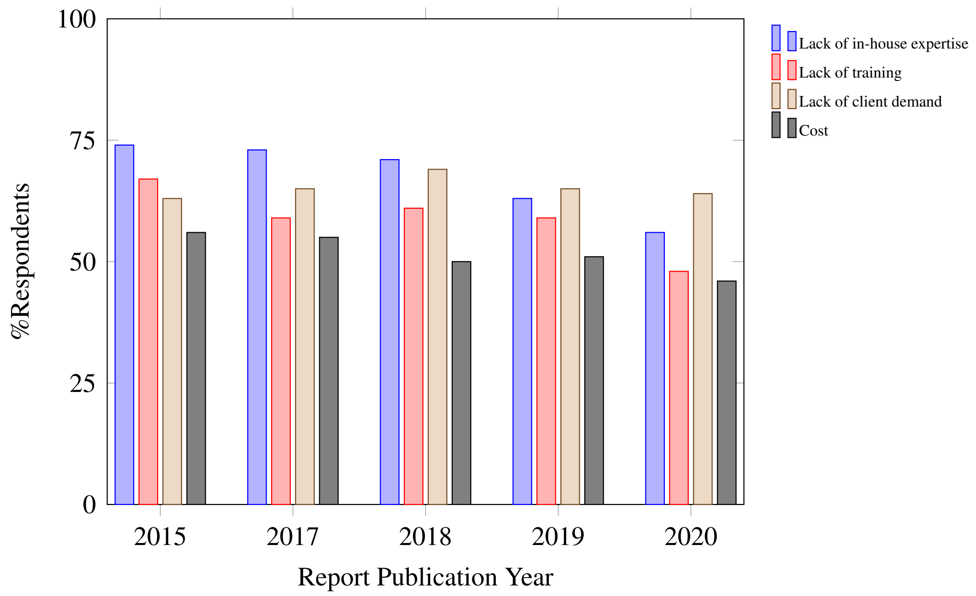


Figure 2.11 Perceived competency-related barriers to BIM adoption. Survey data from the NBS (2015; 2017; 2018; 2019; 2020)

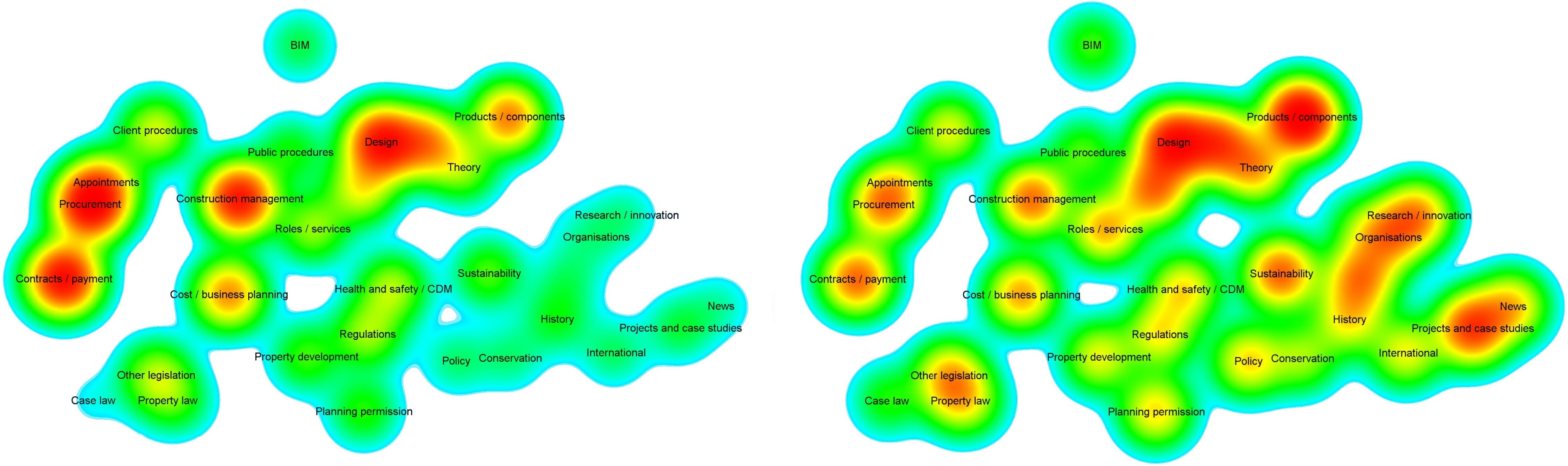
Eadie et al. (2013a) applied a Relative Importance Index to understand the strength of the benefits and barriers to BIM adoption. Their findings corroborated those of the NBS and other similar studies, by indicating that the two biggest barriers were "lack of expertise within the project team" and "lack of expertise within the organisations". The authors comment on this by highlighting this barrier can be reduced in efficacy by providing effective education and training to fill this particular void. It is likely that the barrier is in conjunction with cost and expenditure, considering the capital needed to provide effective training, whereas education is an issue for the individual practitioner and the providing bodies.

Despite the mooted importance of challenging the existing AECO skills provision model, there has been a dearth in literature regarding BIM education and training when compared to other areas within the ever-increasing BIM knowledge domain, as evidenced by Hosseini et al. (2018) and Chegu et al. (2016a). For example, over the ten-year period studied by Santos et al. (2017), only 3, or 0.8%, of the 381 analysed papers focused on BIM education and training. Nevertheless, industry attention has shifted towards the issue of upskilling and workforce competence as the UK moves beyond its Level 2 mandates.

The term *upskilling* has started to emerge as entire sectors face a need to systemically shift in their approaches. Unlike similar terms such as retraining, upskilling instead shifts the training efforts to building on the skills already possessed by individuals to suit their environment which is adapting to further external pressures. Building on Hackitt's condemnation of existing approaches to competence in a regulatory capacity (Hackitt, 2018), a briefing paper by Simpson and Carlton for the UK BIM Alliance (2018) challenged the sector's general understanding of upskilling and competence. The authors called for a delineation of our cognisance surrounding BIM-specific upskilling and its outreaching effects by identifying four components: the definition of BIM competencies, their development, their management, and their assurance. This suggests there is a role for a consistent, unified BIM body of knowledge from which a competency framework could be built and maintained (Bush and Robinson, 2018). Wu et al. (2018) define this body of knowledge as "the systematically curated concepts and nomenclature, knowledge, best practices, standards, and expected outcomes pertaining to BIM and its implementation" (2018, p.4).

However, the challenge of education and training within the AECO industry has never been so complex. As highlighted by Becerik-Gerber, Gerber and Ku (2011), the pressures to embrace new digital approaches are intertwined with an increasing emphasis on achieving a sustainable built environment, with both areas demanding systemic transformations in sector culture and capability. However, research conducted by Design Buildings Wiki has highlighted that existing knowledge pools for BIM remain separated out from any other body of knowledge. This effect is illustrated in Figures 2.12a and 2.12b. Moreover, the knowledge framework[8] underpinning the sector's standards and performance is generally ill-defined, with unregulated publishing processes enabled by the internet threatening to further compromise the integrity of the traditional knowledge production and dissemination model (Designing Buildings Wiki Ltd, 2017).

[8] The knowledge framework underpinning the UK's AECO sector describes "a framework of legislation, regulations, case law, standards, contracts, professional practice and research that establish the boundaries for acceptable performance" (Designing Buildings Wiki Ltd, 2017, p.5)



(a) What people read about

(b) What people write about

Figure 2.12 Emergent knowledge gap between what people read and write about, after Designing Buildings Wiki (2017)

2.4 Concluding Remarks

This chapter has presented an extensive review of the literature by using an emergent approach to inform the study. This was appropriate when considering the need to establish the research within a body of knowledge that is continuously and rapidly expanding as the wider industry BIM discourse matures. The chapter therefore began with a brief overview of the sector's digital timeline, before employing the findings of previous bibliometric-based studies to develop an understanding of the journey of BIM in research settings. In turn, this allowed the study to respond to the broader dialogue surrounding our understanding of BIM within an academic study context, such as corroborating calls for harmonisation within what has become a fuzzy, disjointed research domain with little structure. To do so, the chapter drew on the discussion surrounding the development of a unified BIM taxonomy, as pioneered in the works of Succar (2009) and further developed within the context of adoption by Ahmed and Kassem (2018). In keeping with these efforts, key terms and concepts were delineated in accordance with the proposed taxonomies.

The chapter then discussed macro-level diffusion and reviewed the issues surrounding diffusion assessment within the context of BIM adoption. It drew largely on the body of work published by the NBS and used this to frame our understanding of the perceived extent of BIM adoption in the UK AECO industry. In doing so, this chapter identified several shortcomings of this survey method and suggested a persistent gap exists between rhetoric and reality at varying levels of granularity. Accordingly, the chapter then considered the role of assimilation gaps (Fichman and Kemerer, 1999) by drawing on BIM's appraisal as a systemic, modular construction innovation and aligning adoption behaviour with an individual's ability to assimilate an innovation. Finally, the chapter aligned these concerns with the practice of upskilling by challenging the current education and training landscape surrounding BIM and reiterating calls for a consistent, common body of knowledge to underpin this model. Chapter THREE is concerned with developing the research design and therefore presents the methodology underpinning the study.

CHAPTER THREE

METHODOLOGY AND RESEARCH DESIGN

The manner in which the research is undertaken is significantly dependent on the selection of an appropriate research design. The term *Research Design* is used within this thesis to describe the development of the methodology and the overarching research process. It seeks to capture and articulate the relationships present between the philosophical position of the research and the chosen methods for the present study. This chapter therefore represents a key section within the overall research process, as the production of a coherent research design is critical in achieving the overarching research aim.

The chapter presents the research design and methodology adopted to collect and analyse empirical data. The first part of the chapter follows the pattern of the *Research Onion*, as developed by Saunders et al. (2016), as shown in Figure 3.1. The chapter first presents a discussion surrounding on the position of the research with regards to its philosophical stance and approach to knowledge development. It then identifies various research approaches and evaluates different research methods to ascertain the most appropriate methods to address the research problem. Following on from these discussions, the second part of the chapter explores the adopted research design and justifies the chosen research methods. Ethical considerations are discussed, to ensure rigour is maintained throughout the research process.

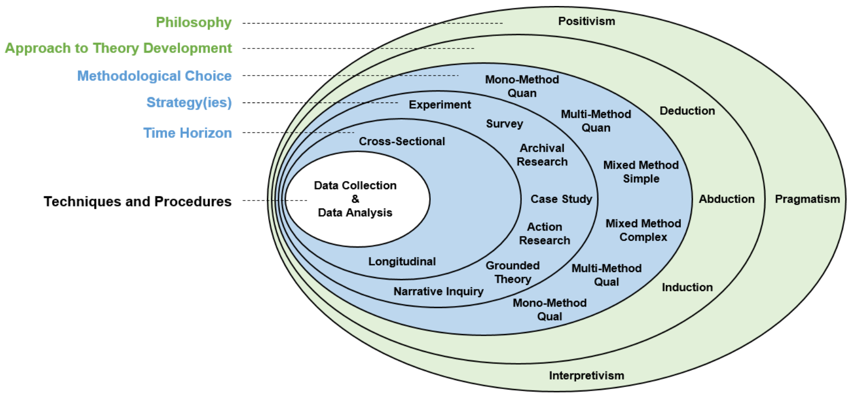


Figure 3.1 Research Onion, adapted from Saunders et al. (2016)

3.1 Research Philosophy

Research philosophy concerns itself with the nature and development of knowledge. The philosophy plays a pertinent role as the underlying intellectual structure informing the research design. The philosophical perspective is distinguished by the ontological, epistemological, methodological, and axiological assumptions they make about the world (Guba and Lincoln, 1994; Creswell and Plano Clark, 2007; Saunders, Lewis, and Thornhill, 2016). Collectively, these metaphysical assumptions position the research within a *research paradigm* [1] grounded on the pattern of their beliefs (Guba and Lincoln, 1994). The paradigm then delimits how knowledge is acquired, how and in which direction theory is developed, and the suitability of the chosen data collection and analysis procedures.

3.1.1 Assumptions

Ontology is the branch of metaphysics concerned with the nature of reality (Guba and Lincoln, 1994; Crotty, 1998). The core tenet of ontology is whether reality is observed from an objectivist (realist) or subjectivist (relativist) position, as posited by Burrell and Morgan (1979). The former asserts that social phenomena is independent and external of social actors, embracing a single, law-driven reality as attributed to the scientific mode of inquiry in the natural sciences (Saunders, Lewis, and Thornhill, 2016). In contrast, the latter asserts that perceptions and actions of social actors create and influence the social phenomena and thus the world around them is in a constant state of change (Bryman, 2016; Saunders, Lewis, and Thornhill, 2016).

Epistemology is concerned with how knowledge is constructed and developed, and more specifically, what constitutes 'acceptable knowledge' in the field of study (Bryman, 2016). Whilst for some research areas this may restrict the decision-making process, the multidisciplinary nature of the current research presents the opportunity for many different

[1] It is interesting to note here that there seems to be very little consistency across academic terminology surrounding the study of knowledge development. This is not a new notion; methodologies, perspectives, and approaches (among others) have consistently been "thrown together in grab-bag style as if they were all comparable terms" (Crotty, 1998, p.3) and that "it is all too easy for social scientists to talk about "paradigms" and mean entirely different things" (Morgan, 2007, p.50). For example, Bryman pins paradigms as epistemological stances (Morgan, 2007; Bryman, 2016), the objective/subjective divide can be seen as affecting all metaphysical assumptions (Saunders, Lewis, and Thornhill, 2016) and terms concerning mode of reasoning range from theory (Bryman, 2016), strategy (Blaikie, 2010), to approach (Saunders, Lewis, and Thornhill, 2016).

types and sources of knowledge to be considered as legitimate for the field of study. For example, the literature review demonstrated that the current study presents significant synergies with Information Systems (IS) theory. The socio-cultural and socio-technical complexities inherent within the IS field alone cannot to be studied from a prescribed set of philosophical assumptions and therefore is not restricted to a single theoretical perspective (Orlikowski and Baroudi, 1991). Similar to business management fields as explored by Saunders et al (2016), the epistemological assumptions surrounding the present research design and selection of methods will therefore be open to interpretation within the delimitation of the recognised paradigm and ontological perspective (Guba and Lincoln, 1994).

The third and fourth philosophical assumptions are methodology and axiology respectively. Guba and Lincoln (1994) define methodological assumptions as dealing with how knowledge is to be found based upon the established ontological and epistemological positions of the research. Axiology is the study of values and ethics dealt with in the research process and has particular relevance within the field of qualitative research (Hiles, 2008). In particular, the values of the research are scrutinised to assess how data is collected and how findings are interpreted in which to derive the most value. In support of this, Saunders et al. (2016) state that "[y]our choice of philosophy is a reflection of your values, as is your choice of data collection techniques", indicating that the judgements made by the researcher throughout the research process provide clarification on how they view and understand the world.

3.1.2 Research Paradigms

The term *paradigm* is typically attributed to Kuhn (1970), as cited in Morgan (2007) and Babbie (2010). Kuhn's observations of scientific progression led to identifying communities of scientists which shared common ontological and epistemological beliefs (Blaikie, 2004). This led to the categorisation of these communities into paradigms based on their metaphysical assumptions. This model can be seen through the works of Burrell and Morgan (1979), Guba and Lincoln (1994), Crotty (1998), and Creswell and Plano Clark

(2007) and is the de facto frame of reference for textbooks exploring research philosophy (e.g Blaikie, 2010; Bryman, 2016; Saunders, Lewis, and Thornhill, 2016). For the purposes of the present thesis, the following three paradigms – Positivism, Interpretivism, and Pragmatism – are evaluated with regards to their ontological, epistemological, methodological, and axiological positions and their relevance to the study.

The traditional paradigms, Positivism and Interpretivism, represent two opposing orthodoxies comprised of mirrored assumptions. Those assuming a Positivist position apply research approaches which are typically affiliated with the natural sciences, such as fact-based investigations and hypothetico-deductive reasoning, to understand social phenomena (Saunders, Lewis, and Thornhill, 2009; DiVanna, 2010; Bryman, 2016). Ontologically, the position assumes an objective stance in which the researcher is independent of the research and postulates that reality can have measurable attributes. This is directly related to the axiological stance adopted by the Positivist, in which the researcher's values do not intervene and rather the findings are judged only by logical inference and with limited bias. For this reason, the Positivist is only concerned with observable phenomena and tends to favour a highly structured, quantitative approach to data collection and analysis.

Interpretivism – alternatively referred to as Constructivism (e.g. Guba and Lincoln, 1994; Creswell and Creswell, 2018) – is the antithesis to positivism; it instead posits that social phenomena cannot be defined objectively nor studied through methods typically employed within the natural sciences (Bryman, 2016; Saunders, Lewis, and Thornhill, 2016). Rather, proponents of Interpretivism position themselves in viewing phenomena through a subjective lens, believing there to be multiple realities built upon the social interaction among actors. As such, qualitative techniques are generally promoted over quantitative to derive complex, rich narratives. This naturally lends itself to the researcher becoming directly involved in the interpretation of the results, which results in axiological implications and debates surrounding the role of bias.

The Interpretivist-Positivist divide has become synonymous with the so-called *qualitative-quantitative divide* (Bergman, 2008) or the *paradigm wars* (Bryman, 2008; Feilzer, 2010). This relates to the traditional Kuhnian concept of paradigm, in which paradigms were believed to be distinct and "incommensurable" (Kuhn, 1970, as cited in Blaikie, 2004). Assuming a firm position on either side of this dominant paradigmatic gulf is problematic; the assumptions made within each are mutually exclusive and designs which subscribe to either Positivism or Interpretivism are therefore restricted to deploying either quantitative or qualitative mode of inquiry based on their prescribed set of beliefs. This makes the weaknesses enshrined within each paradigm difficult to overcome whilst still adhering to philosophical boundaries. For example, Positivism's quest for universal law disregards historical and contextual influence on human action and instead focuses on adopting a circumscribed stance in deterministically explaining observed phenomena, leaving little room for discovery of previously unknown relationships (Orlikowski and Baroudi, 1991). From an Interpretivist perspective, the influence of personal viewpoints and values creates a tendency for bias and restricts the generalisability of the data, which compromises the reliability and representativeness of the data (Bryman, 2016).

However, Morgan argues that "the results from these two "paradigms" for social science research need not be "incommensurate" because each operates in the same socially shared world" (Morgan, 2014b, p.16). This presents an opportunity for the qualitative-quantitative divide to be bridged through the potential application of mixed method research (MMR). By considering and combining qualitative and quantitative strategies, researchers can draw from their strengths and minimise their weaknesses in a single study. The discussion surrounding the application of MMR in philosophical contexts is largely conducted with reference to the Pragmatist paradigm (Morgan, 2014a). However, MMR and Pragmatism are not synonymous (Morgan, 2014a; Saunders, Lewis, and Thornhill, 2016). Rather, a Pragmatist's prerogative is to design a strategy which is appropriate for the overall purpose of the research, which means the employment of a mono- or multi-method strategy is determined instead by the purpose of inquiry and overall research problem (Saunders, Lewis, and Thornhill, 2016).

Unlike Positivism and Interpretivism, Pragmatism places less emphasis on philosophical assumptions and instead concerns itself with the usefulness of the developed knowledge (Morgan, 2014b). A Pragmatist's approach to research "starts with a problem, and aims to contribute practical solutions that inform future practice" (Saunders, Lewis, and Thornhill, 2016, p.143). A Pragmatist recognises that the world can be interpreted in many ways and thus cannot be prescribed to an objective or subjective dichotomy. Rather, ontological and epistemological considerations are superseded by practical and empirical reflexions; action and experience forms the basis for knowledge instead of the nature of reality and truth. Whilst methodological assumptions are still of importance, Pragmatism is less concerned with the nature of the chosen methods and instead demands clarification on why knowledge is being produced in one form and not another (Feilzer, 2010; Morgan, 2014b).

The divorce from the traditional philosophy of knowledge is not without criticism; Maxwell and Mittapalli (2010) believe the Pragmatist stance fundamentally detaches the researcher's inherent beliefs and values from their actions and choices. This risks creating an 'anything goes' perception in which MMR is applied under the guise of Pragmatism but remains methodologically unsound when assessed against ontological and epistemological viability (Bergman, 2008). To this end, claims that research designs can bridge opposing paradigms (e.g. Creswell and Plano Clark, 2007) are also invalid as they undermine the belief systems that each upholds.

However, to suggest Pragmatism is not a philosophical paradigm is inaccurate. Rather, Morgan postulates that social sciences has simply moved towards needing a new methodological agenda for understanding paradigms in philosophy, one which focuses less on metaphysics and instead places more emphasis on its linguistic roots i.e. the study of methods. This is enshrined within John Dewey's [2] doctrine; as Morgan reviews, "Dewey's philosophy of knowledge relies on his concept of inquiry, in which actions as outcomes of inquiry serve as the basis for beliefs" (Morgan, 2014b, p.1048). Advocates of Pragmatism (e.g. Morgan, 2014a; Morgan, 2014b) therefore argue that judgement against a prescribed set of widely-accepted, abstract beliefs merely provides one perspective of social research.

Table 3.1 provides a summary of this section's discussion on the next page.

[2] John Dewey, an American philosopher, is considered as one of the forefathers of Pragmatism and is known for his concept of inquiry (Morgan, 2014a).

Table 3.1 Comparison between the attributes of research paradigms, adapted from Morgan (2007) and Saunders, Lewis and Thornhill (2016)

	Positivism	Pragmatism	Interpretivism
Ontology: What is the nature of reality?	• Rich, external, independent • One true reality (universalism) • Granular (things) • Ordered	• Complex, rich, external • Reality is the practical consequences of ideas • Flux of processes, experiences and practices	• Complex, rich • Socially constructed through culture and language • Multiple meanings, interpretations, realities • Flux of processes, experiences and practices
Epistemology: What is the relationship between the researcher and that being researched?	• Scientific method • Observable and measureable facts • Law-like generalisations/numbers • Causal explanation and prediction as contribution	• Practical meaning of knowledge in specific contexts • True theories and knowledge are those that enable successful action • Focus on problems, practices and relevance • Problem solving and informed future practice as contribution	• Theories and concepts too simplistic • Focus on narratives, stories, perceptions and interpretations • New understandings and worldviews as contribution
Axiology: What is the role of values?	• Value-free research • Researcher is detached, neutral and independent of what is researched • Researcher maintains objective stance	• Value-driven research • Research initiated and sustained by researcher's doubts and beliefs • Researcher reflexive	• Value-bound research • Researchers are part of what is researched, subjective • Researcher interpretations key to contribution • Researcher reflexive
Methodology: What is the process of the research?	• Deductive (testing on *a priori* theory)	• Deductive and / or Inductive (Abductive)	• Inductive

3.1.3 Research Approaches

Aside from developing an understanding of research philosophy, the researcher should decide upon an appropriate mode of inquiry, or research approach (Saunders et al. 2016). The research approach dictates how theories are developed and used within the study, with specific reference to the direction in which the theory is generated and employed.

When considering general scientific reasoning, we typically refer to two modes of inference; these are deductive and inductive reasoning which were built around the traditional linear model of science (Babbie, 2010; Bryman, 2016). However, within the social sciences, an additional school of thought, known as abduction, can be employed. The core differences between the three approaches[3] lie in the order of thought operation between rule, case, and result (Fann, 1970). Other variances can be found in their ontological assumptions, use of concepts and theories, and style of explanation and understanding (Blaikie, 2010). The decision on which approach to adopt stems from its roots in the identified philosophical position of the researcher. The approaches are briefly described below:

1. The first mode of inquiry, known as deduction or deductive reasoning, is concerned with deriving specific empirical observations from general principles, typically through an established theory. Deduction is most often featured within the natural sciences, given its association with mathematical logic. By a process of trial and error, data is used to verify or reject theories and does not have the means to generate further inquiry or predictions. The characteristics of deductive reasoning are a highly structured and replicable methodology and the ability to generalise results, positioning it firmly within the Positivist paradigm.

2. The second mode of inquiry is the antithesis to deduction and is known as induction or inductive reasoning. Induction starts with a set of detailed empirical observations,

[3] Retroductive reasoning is sometimes cited as a separate fourth mode of inquiry (e.g. Blaikie, 2004; Blaikie, 2010). However, it is less established in academic practice and even less so in the social sciences (Blaikie, 2004). The definition of retroduction is also hard to distinguish; abduction has been also called retroduction because of how the process proceeds retroductively from the observation (Paavola, 2004), which potentially obscures correct application in studies which claim to employ it. Retroductive reasoning was therefore disregarded for the purposes of the thesis.

typically collected through qualitative means, which is then analysed for recurring phenomena. The phenomena, if found, can then be used to infer an underlying structure of a system, thereby proposing a theory. By including an understanding of the way in which actors interpret the world around them, the inductive reasoning approach introduces a human aspect when establishing causality (Saunders, Lewis, and Thornhill, 2016), thus aligning itself with Interpretivism.

3. Charles Sanders Pierce, a pioneer of logical inference, believed there to be three stages of inquiry which each employed a unique mode of reasoning (Fann, 1970). Abduction, or abductive reasoning, "as the first stage of inquiry, is concerned with the reasons for proposing a hypothesis" (Fann, 1970, p.59). In other words, the hypothesis is generated to explain a 'surprising' observation (Aliseda, 2006). Through an abductive-deductive-inductive cycle, a dialogue is created therefore between theory-building and empirical observations. From its Pragmatist routes, abduction is typically applied when mixed methods are used in a sequential manner (Morgan, 2007). This is cognisant of the cycle identified by Pierce when we consider the predominantly quantitative and qualitative nature of deduction and induction respectively. Whilst it can be criticised for its fallible nature and ability to generate merely plausible insights, abductive reasoning provides the take-off point for an iterative process by which new theoretical insights can be generated, tested, and verified when used in a transactional "back and forth" manner with deductive and inductive techniques (Morgan, 2007; Mirza et al., 2014). The application of abduction is therefore favoured in emerging arenas of inquiry where information is incomplete (Aliseda, 2006).

The alignment between the research paradigms and the three research approaches are noted in Table 3.2.

Table 3.2 Comparison between research approaches, adapted from Saunders et al. (2016)

	Deduction	**Induction**	**Abduction**
Typical Approach	Quantitative /Positivist	Qualitative /Interpretivist	Mixed Methods /Pragmatist
Logic	When the premises are true, the conclusion must also be true	Known premises are used to generate untested conclusions	Known premises are used to generate testable conditions
Generalisability	From the general to the specific	From the specific to the general	From the interactions between the specific and the general
Use of Data	To evaluate propositions or hypotheses related to an existing theory	To explore a phenomenon, identify themes and patterns and create a conceptual framework	To explore a phenomenon, identify themes and patterns, locate these in a conceptual framework and test this through subsequent data collection and so forth
Inferences	Generality	Context	Transferability
Theory	Falsification or verification	Generation and building	Generation or moderation; incorporating existing theory where appropriate, to build new theory or modify existing theory
Flow	Rule $\Longrightarrow$ Case $\Longrightarrow$ Result	Result $\Longrightarrow$Case $\Longrightarrow$Rule	Rule $\Longrightarrow$ Result $\Longrightarrow$ Case $\rightarrow$ *start again and refine*

3.2 RESEARCH METHODS

As illustrated by the change in shade in the Research Onion (Figure 3.1), the decision-making supporting the research design departs from philosophical, abstract concerns and moves towards practical considerations. The decisions which are made henceforth will provide the tools to facilitate an effective and coherent approach to data collection and analysis. Deciding upon the most appropriate methodology will be directed by the overarching philosophy and the chosen approach discussed earlier in this chapter.

Accordingly, addressing each layer of the research onion sequentially will provide a discursive structure on which to base the research design. The structure begins with the broad consideration of methodological choice, which in turn informs the choice of research strategy and the time horizon of the study. Data collection techniques and procedures will be outlined with a view to selection when reflecting upon the chosen research design in the next section.

3.2.1 Methodological Choice

The third layer in the research onion addresses the researcher's methodological choice, which concerns whether a quantitative, qualitative, or mixed methods model is most appropriate for answering the present research problem. The choice of model guides how the study is conducted and how findings are subsequently accumulated and analysed. Whilst framed as a singular choice, the methodological choice concerns a two-step decision-making process. As illustrated in Figure 3.1, Saunders et al. (2016) describe the first decision as whether the study should employ a mono method (i.e. a single method) or multiple methods. A mono method approach will exclusively engage either a quantitative or qualitative strategy, whereas multiple methods range from multi-method quantitative, multi-method qualitative, or a mixed methods design. The journey through the decision-making process is informed by the purpose of the study and by the philosophical lens of the adopted paradigm. However, practical considerations will also influence how data are collected and analysed (Bryman, 2016).

A broad distinction between quantitative and qualitative research is whether the data collected is numeric or non-numeric, the latter of which can range from text and other forms of media, such as images whilst the former is just concerned with numbers (Saunders, Lewis, and Thornhill, 2016). An alternative distinction can be made between whether the questions asked and responses collected are closed-ended (quantitative) or open-ended (qualitative) (Creswell and Creswell, 2018).

Although not exclusively, quantitative strategies tend to fall into the camp of the Positivist paradigm with deductive reasoning, whereas qualitative strategies are usually associated with an Interpretivist philosophy and favour an inductive reasoning approach (Table 3.2). However, a debate exists surrounding the deterministic relationship often purported of the quantitative-qualitative dichotomy and their supposed philosophical assumptions. Bryman (2016) proposes there are two versions of the debate: an epistemological version and a practical version. If assuming the epistemological version of the debate, philosophical assumptions are either cited as an argument against merging quantitative and qualitative methods as they are incompatible (Bryman, 2016) or they are neglected as an issue altogether (Blaikie, 2010). Conversely, if assuming the practical version of the debate, methods are instead viewed as autonomous, regardless of the distinctions made between assumptions, and thus greater prominence is given to the strengths and practicalities of data-collection and data-analysis techniques. To this end, a parallelism exists with the belief system held by Pragmatism in which the purpose of the study is used to frame their methodological choice. Both steps involved in the decision-making process are thus contingent on the nature of the research objectives (Saunders, Lewis, and Thornhill, 2016). As discussed earlier from a philosophical standpoint, this enables a study adopting the Pragmatist paradigm to consider a mixed methods strategy if it is appropriate to addressing the research problem.

As an emerging methodology in the social sciences, it is recommended to define and describe the basic approach to using mixed methods (Creswell and Creswell, 2018). Mixed methods research (MMR) is defined by Creswell and Plano Clark as "a research design with philosophical assumptions as well as methods of inquiry [...] Its central premise is that the use of quantitative and qualitative data approaches in combination provides better understanding of research problems than either approach alone" (Creswell and Plano Clark, 2007, p.5). Mixed methods can be employed either concurrently or sequentially (Saunders, Lewis, and Thornhill, 2016; Creswell and Creswell, 2018). Concurrent mixed methods research involves the collection of data using quantitative and qualitative techniques separately but within a single phase or study (Creswell and Plano Clark, 2007). Both sets of results are then interpreted together using triangulation procedures to provide a more comprehensive view of a single research objective. Sequential mixed methods research introduces a multi-phase approach in which one phase acts as a precursor to another phase. The techniques are deployed during separate points in time in a manner consistent with mono-method approaches; however, it is still important to justify the relationship between the components from the outset. The multi-phase design is dependent on the purposes enshrined within the research objectives, i.e. whether the research seeks to be exploratory, descriptive, or explanatory (Blaikie, 2010).

The characteristics and tendencies of quantitative, qualitative, and mixed methods research are presented in Table 3.3 on the next page.

Table 3.3 Methodology choice characteristics and tendencies, adapted from Creswell and Creswell (2018)

Tendencies		Quantitative	Mixed Methods	Qualitative
Philosophical Assumptions		• Positivism	• Pragmatism	• Intepretivism
Strategy of Inquiry		• Surveys • Experiments	• Convergent (or Concurrent) • Explanatory Sequential • Exploratory Sequential • Complex designs with embedded core elements (i.e. mixing the above)	• Phenomenology • Grounded Theory • Ethnography • Case Study • Narrative
Methods	**Questions**	• Instrument-based questions	• Open-ended questions • Closed-ended questions	• Open-ended questions
	Data	• Performance data • Attitude data • Observational data • Census data	• Multiple forms of data drawing on all possibilities	• Interview data • Observation data • Document data • Audiovisual data
	Analysis	• Statistical analysis	• Statistical and text analysis	• Text and image analysis
	Interpretation	• Statistical interpretation	• Across databases interpretation	• Themes and patterns interpretation
Position of the Researcher		• Tests or verifies theories or explanations • Identifies variables to study • Relates variables in questions or hypotheses • Uses standards of validity and reliability • Observes and measures information numerically • Uses unbiased approaches	• Collects both quantitative and qualitative data • Develops a rationale for mixing • Integrates the data at different stages of inquiry • Presents visual pictures of the procedures in the study	• Positions themselves • Collects participant meanings • Focuses on a single phenomenon • Brings personal values into the study • Studies the context of participants • Validates the accuracy of findings • Creates an agenda for change or reform • Collaborates with the participants

3.2.2 RESEARCH STRATEGIES

Devising a research strategy involves developing a plan for how the research problem is to be addressed by which type of data. The deployment of research strategies is generally quite flexible within the boundaries set by the methodological choice; strategies do not inherently rank in superiority, nor are they mutually exclusive and restrict the researcher to applying only one strategy for one problem (Saunders, Lewis, and Thornhill, 2016). For the purposes of the current study, the strategies illustrated within the research onion diagram are evaluated, with respect to the type of data they typically collect and their key strengths and weaknesses. Whilst an indication of the available methods will be touched upon, thorough examination of the final selection will be facilitated when discussing the adopted research design in the next section.

The following series of tables presents the research strategies available to the researcher; Table 3.4 concerns research strategies which are predominantly associated with methods which collect quantitative data and Table 3.5 concerns those which can be used with either quantitative or qualitative data. Qualitative strategies, such as ethnography, phenomenology, grounded theory, and action research, have not been evaluated as they would be too intensive and time-consuming for the research timeframe. However, it is likely that qualitative techniques may play a secondary role, so a brief insight is provided in Table 3.6.

Table 3.4 Overview of strategies which are typically quantitative

Strategy and Definition	Strategy Characteristics
Experiment - "An experimental design systematically manipulates one or more variables in order to evaluate how this manipulation impacts an outcome (or outcomes) of interest" (Creswell and Creswell, 2018, p.147)	**Key Strengths**: Due to the robustness and precision advocated by experimental design as demonstrated in the natural sciences, experiments as a strategy are used as a yardstick for nonexperimental strategies because of their strong internal validity and scientific rigour (Bryman 2016; Saunders et al. 2016). In addition, sources of invalidity can be logically controlled (Babbie 2010). Experimental designs are often replicable and the focus on one isolated, manipulable variable allows for effective monitoring of causal effects (Babbie, 2010). **Key Weaknesses**: As experiments are often conducted in controlled environments, e.g. laboratories, they are unlikely to represent realworld conditions. The results will be less generalizable to a wider population in such conditions compared to field-based experiments (Babbie, 2010; Saunders, Lewis, and Thornhill, 2016). **Data Collection Techniques**: Experiments can be classical experiments, quasi-experiments, or within-subject experiments.
Questionnaire Survey - "A survey design provides a quantitative description of trends, attitudes, and opinions of a population, or tests for associations among variables of a population, by studying a sample of that population" (Creswell and Creswell, 2018, p.147).	**Key Strengths**: Surveys are able to employ large samples from a sizeable population for the purposes of describing their characteristics (Babbie, 2010). Saunders et al. state that "a survey strategy should give you more control over the research process and [. . .] it is possible to generate findings that are statistically representative of the whole population at a lower cost than collecting the data for the whole population" (Saunders, Lewis, and Thornhill, 2016, p.182). **Key Weaknesses**: The amount and breadth of data collected is limited when compared to other strategies because of the reliance on the goodwill of the participant (Saunders, Lewis, and Thornhill, 2016). The requirement to standardise the data often results in superficial treatment of complex topics and variables (Babbie, 2010). Babbie also argues that surveys cannot measure social action as they rely on self-reports from the respondents, indicating weak validity. **Data Collection Techniques**: Surveys are usually conducted using questionnaires or structured interviews (Bryman, 2016; Saunders, Lewis, and Thornhill, 2016).

Table 3.5 Overview of strategies which can apply either, or both, quantitative and qualitative techniques

Strategy and Definition	Strategy Characteristics
Archival/Documentary Research/ Secondary Data - "The analysis of data by researchers who will probably not have been involved in the collection of those data, for purposes that may not have been envisaged by those responsible for the data collection" (on Secondary Analysis: Bryman, 2016, p.696)	**Key Strengths**: The use of secondary data sources is unobtrusive, which can be advantageous in sensitive contexts or when data is needed at a large scale (Saunders, Lewis, and Thornhill, 2016). It also tends to be quicker and cheaper to conduct, as data is already collected and oftentimes processed (Babbie, 2010). For example, Government data, such as censuses, are widely available online and come in a variety of formats, e.g. raw data, final reports, historical data, etc. (Saunders, Lewis, and Thornhill, 2016). **Key Weaknesses**: It is often unknown when accessing secondary sources of the true intentions of the initial investigator. This hinders the researcher in understanding the social context at the time of data collection, having consequential effects on interpretation of the data (Hammersley, 1997, as cited in Bryman, 2016). This can compromise the validity and overall quality of the collected data (Babbie, 2010; Saunders, Lewis, and Thornhill, 2016).
Case Study - "The in-depth examination of a single instance of some social phenomenom, such as a village, a family, or a juvenile gang" (Babbie, 2010, p.309)	**Key Strengths**: Case studies provide the researcher with a flexible approach to data collection and analysis by combining multiple research methods, which in many instances comprise a mixed method design (Saunders, Lewis, and Thornhill, 2016; Creswell and Creswell, 2018). They are also beneficial for in-depth longitudinal and comparative studies (Bryman, 2016). The real-life context in which they are placed provides the researcher with rich insights into particular phenomenom and are well-placed to drive, measure, and understand action (Saunders, Lewis, and Thornhill, 2016). **Key Weaknesses**: The generalisability and theory testing abilities of cases studies is often criticised (Blaikie, 2010), which can be somewhat reduced by introducing multiple cases (Babbie, 2010). The intensive nature of case study research requires the researcher to be explicit in their resource needs (i.e. time, access, and potential costs), in addition to overtly stating the boundaries of the study and reasoning behind how the studies are conducted (Saunders, Lewis, and Thornhill, 2016).

Table 3.6 Qualitative data collection techniques and characteristics, adapted from Creswell and Creswell (2018)

Technique and Definition	Options within Procedures	Key Strengths	Key Weaknesses
Observations: "A qualitative observation is when the researcher takes field notes on the behaviour and activities of individuals at the research site" (Creswell and Creswell, 2018, p.186)	• Complete participant (research conceals role) • Observer as participant (role of researcher is known) • Participant as observer (observation role secondary to participant role) • Complete observer (researcher observes without participating)	• Researcher has a first-hand experience with participant • Researcher can record information as it occurs • Unusual aspects can be noticed during observation • Useful in exploring topics that may be uncomfortable for participants to discuss	• Researcher may be seen as intrusive • Private information may be observed that the researcher cannot report • Researcher may not have good attending and observing skills • Certain participants (e.g.) children may present special problems in gaining rapport
Interviews: "[Qualitative interviews] involve unstructured and generally open-ended questions that are few in number and intended to elicit views and opinions from the participants" (Creswell and Creswell, 2018, p.187)	• One-on-one, in-person interview • Telephone • Focus group • E-mail Internet interview	• Useful when participants cannot be directly observed • Participants can provide historical information • Allows researcher control over the line of questioning	• Provides indirect information filtered through the views of interviewees • Provides information in a designated place rather than the natural field setting • Researcher's presence may bias responses • Not all people are equally articulate and perceptive
Documentary Research: Document types can be categorised as raw (unprocessed) or compiled (summarised) data (Saunders, Lewis, and Thornhill, 2016). To be applicable to social research, documents must be able to be analysed, be relevant to the concerns of the researcher, and not have been produced specifically for the purposes of social research (Bryman, 2016).	• Keeping a research journal for the duration of the study • Public documents – e.g. minutes of meetings or newspapers • Private documents – e.g. journals, diaries, or letters	• Enables a researcher to obtain the language and words of participants • Can be accessed at a time convenient to researcher – an unobtrusive source of information • Represents data to which participants have given attention • As written evidence, it saves a researcher the time and expense of transcribing	• Not all people are equally articulate and perceptive • May be protected information unavailable to public or private access • Requires the researcher to search out information in hard-to-find places • Requires transcribing or optically scanning for computer entry • Materials may be incomplete, not be authentic or inaccurate

3.2.3 Time Horizon

The time horizon of a study considers whether data is collected at one point in time or at multiple time points over a specified period, referred to as cross-sectional and longitudinal designs respectively. Adopting a longitudinal perspective over a cross-sectional design is typically preferred within social sciences for the purposes of assessing causality in social processes and social change (Blaikie, 2010). The absence of time ordering in an explanatory cross-sectional design presents a significant limitation as unlike its counterpart it cannot imply causality between variables (Babbie, 2010; Bryman, 2016). Rather, cross-sectional designs are restricted to only examining the strength of relationships between non-manipulable variables, with the direction of causality being established through *a priori* assumptions. However, time, cost, and resource constraints often limit research designs to rejecting a longitudinal approach, particularly if qualitative methods are favoured.

3.2.4 Unit of Analysis

A further consideration that is not explicitly outlined within the Research Onion is the unit of analysis. The unit of analysis describes the entity or subject being studied. Whilst this entity can also be an object or thing, the predominant units of analysis in the social sciences are individuals or defined groups of people (Long, 2011). For example, Poirier et al. (2017) define the individual project team member within their study as the unit of analysis, whereas Cho and Kim (2002) and Dainty et al. (2017) identify the organisation as the unit of analysis for their respective studies. Alternatively, the unit of analysis can also focus on processes and activities rather than people, such as on-site construction activities (Matthews et al., 2018), an organisation's internal processes and IT systems (Krystallis et al., 2016), and processes being implemented within project settings (e.g. Mahalingam, Yadav, and Varaprasad, 2015; Sackey and Akotia, 2017; Papadonikolaki, 2018).

The nature of the unit of analysis will have implications on which research methods should be employed; it can often be the case that the unit of observation does not align with the identified unit of analysis based on what can and cannot be practically measured (Long, 2011). For example, this could relate to how well the chosen sample (unit of observation) represents a wider population (unit of analysis) and therefore how generalisable the data is. Furthermore, the unit of analysis must be appropriate when considering the scale or level of analysis of the research, as established in Chapter TWO. For example, studying an organisation's internal policy would be an appropriate unit of analysis for meso-level research, but would unlikely draw meaningful conclusions at the macro-level. Therefore, the chosen research design should recognise and attempt to mitigate these challenges, whilst ensuring inference can still be meaningfully drawn at the correct unit of analysis.

3.3 The Adopted Research Design

This section outlines the rationale behind the adopted research design by drawing on the discussions having taken place within this chapter thus far. It aligns the research philosophy in Section 3.1 with the practical method choices in Section 3.2.

3.3.1 Design Rationale

Determining the process of disciplined inquiry provides credibility to the researcher's studies and decisions, and is generally constructed through the their identified position within a paradigm (Crotty, 1998). Following the discussions facilitated in the initial portion of this chapter, Pragmatism using abductive reasoning forms the philosophical structure underpinning the present study. The reasons behind this selection can be summarised by the following points:

- Whilst the dominant approach in IS research is to adopt a Positivist stance, adopting a single, purist paradigm with strong, divisive ontological and epistemological assumptions, such as those espoused by Positivism and Interpretivism, is unsuited to the qualities held by the researcher. Rather, the researcher identifies themselves more so with the Pragmatist belief system which assigns less importance to philosophical assumptions and more value to the appropriateness of research methods and knowledge production in view of addressing the research objectives, such as identifying an appropriate and observable unit of analysis.
- Given the vastly understudied and yet increasingly relevant area in which the present

thesis is situated, the literature review provided a vehicle by which research objectives could develop naturally to address the emergent issues. The literature identified a great need for further exploration into BIM competency gaps and the associated role of the individual social actor in BIM adoption. However, the literature review also provided justification to develop a conceptual framework by which to identify and measure these gaps and to generalize findings to an industry-scale. The research objectives therefore reflect the principles enshrined within both Interpretivism and Positivism respectively, thereby positioning the study in a strong position to adopt MMR, as is appropriate to each of the generated questions. This would satisfy the core tenet of Pragmatism by using the type of knowledge demanded of the questions to structure the research design.

- Pragmatism is less prescriptive towards adopting a deductive or inductive mode of inquiry. Rather, Pragmatism advocates abductive reasoning as the first stage of enquiry, which then initiates a back-and-forth movement between data and theory, thereby alternating between deduction and induction approaches in later stages. Moreover, abductive reasoning requires a surprising observation to serve as the basis for the research problem. The apparent gap in BIM adoption figures, as discussed extensively in the literature review, fulfils this role. Whilst the researcher is suggesting micro-level factors may be explaining this gap, the application of an abductive research approach allows the researcher to adapt as understanding grows through the iterative dialogue abduction encapsulates.

The development of the research design is also guided by the unit of analysis. The literature review established that the *level* of analysis is central to the research narrative by establishing that BIM adoption is studied at the micro-, meso-, or macro-levels, and to a given level of granularity - refer to Table 2.7. Therefore, to frame the decisions surrounding the adopted research design, the unit of observation is BIM adoption and assimilation by the individual industry practitioner at the micro-level for generalisation to the AECO industry at the macro-level.

3.3.2 Exploratory Sequential Design

As previously discussed, the researcher's position as a Pragmatist does not automatically denote synonymy with adopting a MMR design, nor does it completely disregard the debate surrounding the deterministic relationship often purported of the quantitative-qualitative dichotomy. If assuming the epistemological version of the debate, the supposedly irreconcilable philosophical assumptions are either cited as an argument against the application of MMR (Bryman, 2016) or neglected as an issue altogether (Blaikie, 2010). Conversely, if assuming the practical version of the debate, methods are instead viewed as autonomous, regardless of the distinctions made between assumptions, and thus greater prominence is given to the strengths and practicalities of data-collection and data-analysis techniques. To this end, adopting an MMR methodology is not necessarily superior to mono-method. Notwithstanding the practical considerations such as the time, resources, and expertise required in its application, it is therefore recommended for researchers to produce sound rationale for the adoption of MMR and the configuration of choice (Bryman, 2016).

In accordance with the pragmatistic advocation for the practical version of the debate, the research employs an exploratory sequential design to address the research objectives. This describes a two-stage process in which an initial exploratory study using qualitative methods precedes the collection of empirical, quantitative data for a descriptive study (Saunders, Lewis, and Thornhill, 2016). Scope exists for the study to follow with a third step which introduces an explanatory element to overcome the limitations presented by adopting a cross-sectional design. However, as time constraints govern the present study, the expansion into a sequential three-phase design will instead be discussed in Chapter NINE as a future consideration. The full research design is illustrated in 3.2.

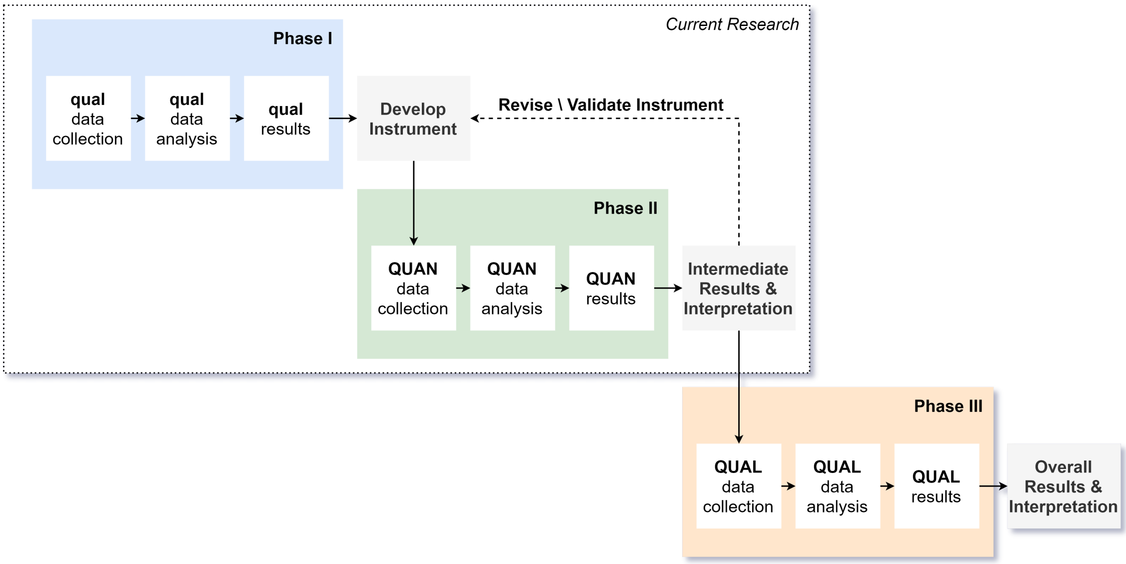


Figure 3.2 Diagrammatic representation of the adopted qual ⟶ QUAN research design, with suggested Phase III (⟶ QUAL) explanatory element. NOTE: The change in from lower to upper case lettering denotes secondary and primary methods respectively. See Creswell and Plano Clark (2007) for further discussion.

A multi-phase design which employs a mixed methods model recognises that social research is an iterative and dynamic process. By conducting the study in phases, initial findings can be used to shape and inform the design of the subsequent phase, enabling the study to adapt as new themes and insights emerge. The first phase, Phase I, of the research design therefore consists of an exploratory study which builds upon the emerging themes and review queries developed during the literature review for the purposes of generating an appropriate conceptual framework for the thesis. The framework will provide a clear picture of the phenomenon against which data can be collected (Saunders, Lewis, and Thornhill, 2016). The second phase, Phase II, comprises a descriptive study which uses the framework to derive a series of hypotheses to be tested using statistical techniques.

3.3.3 Phase I: Exploratory Study

Conducting exploratory research allows a deeper understanding of an issue with the advantage of being adaptable to change as new insights emerge (Saunders, Lewis, and Thornhill, 2016). The first phase of the research therefore consists of an exploratory investigation into the roles of BIM adoption and maturity from a multi-level perspective. Phase I aims to build upon the narrative constructed during the literature review which identifies this relationship as a largely understudied area in not only the conversations surrounding the BIM discourse, but also in the well-established general technological innovation adoption theory. To this end, the absence of an existing, suitable instrument has led to adopting the instrument development model of exploratory design (Creswell and Plano Clark, 2007). This model places emphasis on the development and testing of a quantitative instrument by using items and scales informed by the qualitative findings of exploratory studies.

The qualitative method chosen for Phase I is the semi-structured focus group interview technique. The focus group method enables more than one interviewee to be interrogated at a single point in time. This enables the study to delve into "the ways in which individuals discuss a certain issue as members of a group, rather than simply as individuals" (Bryman, 2016, p.501). The present study advocates a multi-level perspective and therefore it is believed that value can be derived from interactions between individuals who sit at various points in the BIM upskilling and adoption chain, such as industry practitioners, education and training providers, and policymakers. This provides an advantage over conventional one-to-one interviews typically employed within the social sciences; rather, responses can be probed further through discussions with other participants which may be overlooked otherwise. This is particularly useful for the purposes of exploration. Furthermore, the researcher can play a lesser role, thereby reducing potential bias in addition to limiting any influence their presence has on the responses; this is because a certain amount of control is relinquished to the group which can make it easier for participants to be more honest and open with their concerns (Bryman, 2016). Again, this provides value to the exploratory sequential design which uses the qualitative findings as an important point of departure for instrument development.

The practical considerations in facilitating the focus group interviews, such as selecting the participants, transcription procedures, and interview questions, are discussed in Chapter FOUR.

3.3.4 Phase II: Descriptive Study

Exploratory studies seldom satisfy the research problem as a standalone solution due to the inability to extrapolate the findings to a larger population (Babbie, 2010). Rather, the exploratory Phase I of the present study aims to provide the relevant tools to construct an appropriate conceptual model to address the central research problem. To this end, the second phase of the research concerns itself with observing and describing the strength of relationships between the emergent variables. The descriptive nature of the study naturally lends itself to adopting a quantitative approach, allowing statistical evidence to be gathered on these relationships. As this demands the collection of standardised data from across a sizeable population, it is posited that the questionnaire survey technique is the most appropriate method for answering the Phase II research objectives.

As illustrated in Figure 3.3, there are many modes of survey administration to consider within the categories of self-administered questionnaire and structured interview, which were introduced in Table 3.4. Each mode is characterised by differing attributes related to how data is collected. The choice of which mode to adopt is thus reliant on the data required by the research objectives and the resources available to the study (Saunders, Lewis, and Thornhill, 2016). The target population of the study is the AECO industry which is large and inherently heterogeneous. To this end, the present study uses a combination of self-administered modes, known as mixed mode, in an attempt to capture a wide range of participants which is representative of the population.

Self-administered surveys are cheap and quick to administer and convenient for the respondent (Bryman, 2016). In recent years, the rapid normalisation of web-based technology has enabled internet-enabled surveys to become a prominent self-administered mode of choice, particularly over costly paper-based delivery mechanisms (Bryman, 2008; Babbie, 2010). As an integral feature of internet-based modes, data is collected electronically which decreases the time required for data entry and processing (Saunders, Lewis, and Thornhill, 2016). However, Saunders et al.(2016) identifies that internet-based modes tend to suffer with very low response rates when compared to structured interview techniques.

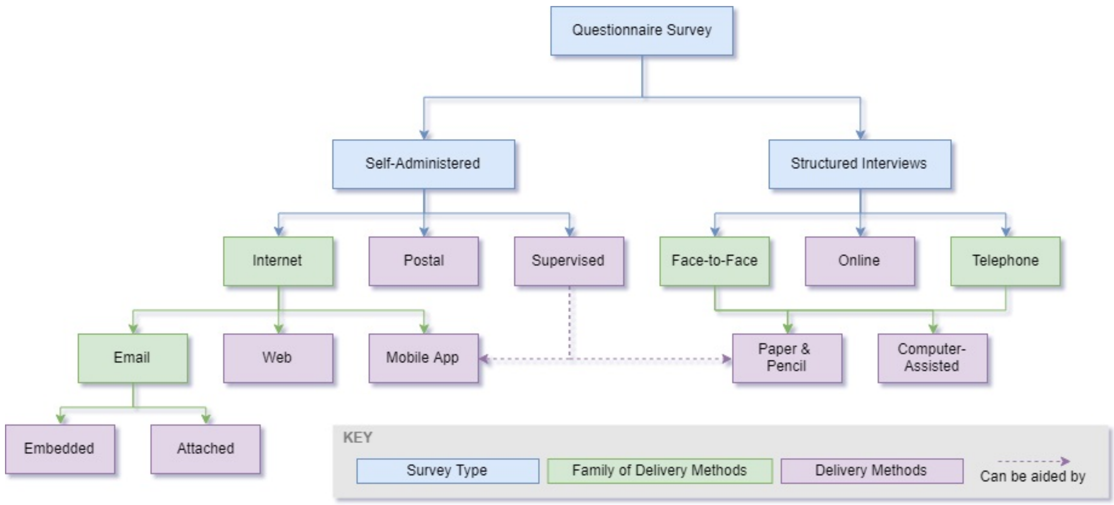


Figure 3.3 Types of question survey and distribution methods, adapted from Bryman (2016) and Saunders et al. (2016)

This is an important consideration in the design of the questionnaire survey (e.g. the length of time it takes to complete will likely affect the number of drop-outs) and in the interpretation of results (e.g. is the sample representative of the population?).

As highlighted by Figure 3.3, multiple internet-enabled modes exist: these span email-, web-, and mobile application-based platforms. The variety of internet-based modes has increased the popularity of mixed mode surveys in which greater coverage can be achieved; however, ambiguity still persists surrounding whether the mode of administration matters and, if so, to what extent this mode effect occur (Bryman, 2016). Hence, for best efforts in maintaining consistency in a mixed mode survey, a single, online questionnaire tool will be sought, from which the individual modes can be generated and distributed. This will reduce the risk of variation which can be attributed to how respondents complete the questionnaire survey by providing them with a visually similar experience (Bryman, 2016).

The practical considerations, including how the sample is selected, the configuration of the mixed mode survey, and how the conceptual model is operationalised for the purposes of the questionnaire survey, are discussed in Chapter SEVEN

3.4 Ethical Considerations

A core concern when conducting research involving external participants are the ethical considerations which ensure respect and integrity are maintained throughout the research process. Adequate steps should be taken to overcome the main areas of ethical concern, which are: the potential harm to participants, not being able to acquire informed consent or ensuring voluntary participation, compromising confidentiality and anonymity, and deceiving respondents (Babbie, 2010; Bryman, 2016).

The present study is considered to be low-risk. However, in accordance with research integrity guidelines, a covering information sheet is to be provided to each participant prior to commencing either data collection procedure. The sheet, or page in the instance of the online questionnaire survey, will explain the purpose of the research, how the data will be used, treated, and stored, and instructions on how to participate. The expected time for participation is to be stated and respondents will be free to withdraw at any point without reason. Informed consent for the terms set out in the information sheet and the voluntariness of the participant is to be obtained through the respondent's signature prior to the commencement of the focus group interview and through a mandatory checkbox on the online questionnaire platform. Contact details for the research team will also be provided should the respondents have any concerns or queries. The information sheet for the focus group interview is provided in Appendix C, whilst the questionnaire survey in Appendix D presents the information as a gateway webpage to the online instrument.

In adherence to Edinburgh Napier University's Code of Practice on Research Integrity, an application was submitted to the School of Engineering and the Built Environment's Integrity Lead for approval. The completed form can be found in Appendix C.

3.5 Concluding Remarks

This chapter has presented the research methodology and design. The philosophical foundations of the research were highlighted, which in turn informed the choices made with regards to the research approach and methods. In line with pragmatist principles, this study follows an abductive research approach which stresses the importance of dialogue between theory and empirical research. In response to this stance, a multi-stage research design was developed. The present study will focus on the initial qual $\longrightarrow$ QUAN stages, beginning with an exploratory phase which has been designed to augment the emergent themes from the literature review. Chapter FOUR will therefore discuss the exploratory data collection and findings of Phase I.

Chapter FOUR

Phase I: An Exploratory Study

This chapter presents the first data collection and analysis phase of the research. The narrative provided in this chapter departs from the broader methodological discussions in Chapter THREE and delves into the practical implications and considerations surrounding how the exploratory study is to be conducted. As discussed in Chapter THREE, this phase of the research design employs an exploratory approach using focus group interviews (FGIs) as the qualitative data collection method. Phase I is designed to augment the emergent findings of the literature review and further establish the theoretical grounding of the research.

The chapter employs the Stewart et al. (2007) nine-step guide as the model for designing, planning, and conducting the focus groups. Figure 4.1 illustrates these sequential stages and frames them against the structure of the chapter. Firstly, the intended contribution of Phase I is contextualised by outlining its purpose as derived from knowledge gaps presented within the literature review. These are presented as themes, designed to stimulate exploratory discussions among participants. The design of the focus groups is then introduced and discussed, which outlines the target group composition and the rationale behind the size and number of focus group sessions. The chapter then discusses the practical considerations concerning data collection and analysis. The empirical results of the exploratory study are then presented and discussed using the emergent themes as the analytical framework.

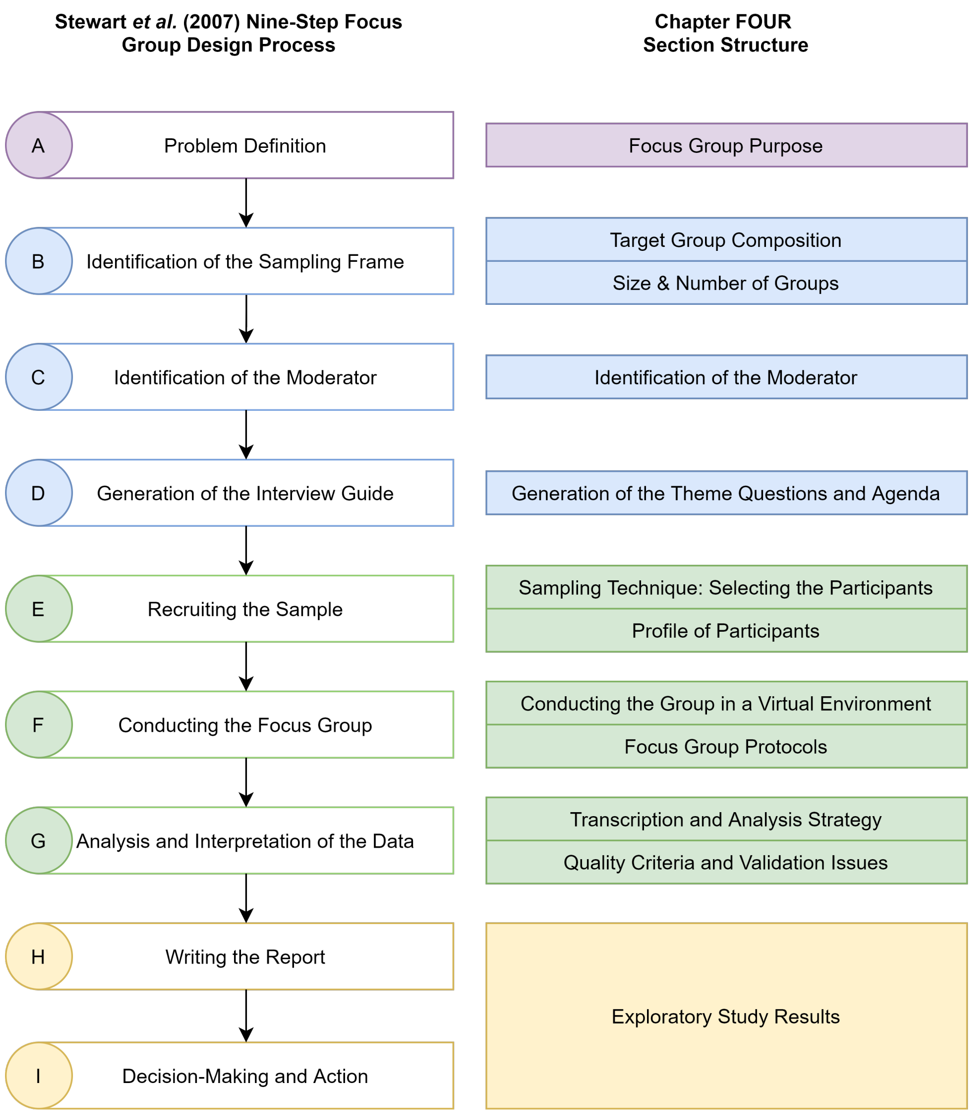


Figure 4.1 Focus group process flow, adapted from Stewart et al. (2007)

4.1 Exploratory Study Purpose

To reiterate the rationale presented in Chapter THREE, the purpose of conducting an exploratory study is to augment the findings of the literature review by capturing the views of relevant stakeholders within a forum context. The exploratory study, which forms Phase I of the overall research design, therefore serves as a preamble to developing an appropriate model which can address the research problem.

The focus group technique is preferred over conducting individual interviews as it is believed that the interaction between participants would bring added value to the discussion when considering the emergent nature of the research problem. As stated by Gu and London in their BIM adoption study, focus groups offer "the collection of more in-depth data on BIM adoption [and] also provide a forum for the different disciplines within the AEC industry to share and clarify their views on various BIM adoption issues such as common understanding of benefits, hurdles, requirements and expectations of BIM" (2010, p.990). Other BIM adoption studies which utilise the focus group technique include Singh (2014), Rogers et al. (2015), and Liu et al. (2017).

The literature review highlighted two core themes: the levels of analysis at which BIM adoption can be studied, and the efficacy of BIM adoption. The former considers the dialogue and tensions that may exist between macro-level diffusion and the individual adopters at the micro-level, while the latter suggests that the efficacy of BIM adoption is a function of assimilation and upskilling behaviours. These key themes are tabulated and presented in Table 4.1. The purpose of the focus group is to therefore further investigate and empirically validate these themes by drawing on the opinions of AECO-based professionals with industry, policymaking, or upskilling backgrounds.

Table 4.1 Focus group key themes and agenda

	Macro-Level	**Micro-Level**
BIM Adoption and Use	**Theme 1:** BIM Adoption Rate Assessments	**Theme 2:** Perceived Adoption / Use
Upskilling and Competency	**Theme 3:** Industry Upskilling Provision	**Theme 4:** Individual BIM Assimilation

4.2 FOCUS GROUP DESIGN AND PRINCIPLES

This section addresses the principles underpinning Phase I of the research methodology, which concerns the exploratory focus groups. It serves as a preamble to the empirical data collection by setting out the design and scope of the exploratory study and by outlining the targets against which the effectiveness of the method can be assessed. This section also presents the development of the focus group agenda as guided by ‘Theme Questions’ derived from the findings of the literature review.

4.2.1 Target Group Composition

When considering participants for group data collection activities, it was necessary to consider the composition of the wider group and the degree of alignment between participants' characteristics (Guerrero and Xicola, 2018). To achieve an appropriate group composition, Liamputtong (2011) highlight three areas of concern to consider: the degree of group homogeneity (or conversely heterogeneity), whether the participants have shared experiences, and whether the participants are acquaintances or strangers.

By understanding the desired group composition, an appropriate sampling technique can then be applied and suitable participants can be recruited. Framing this decision as a simple dichotomy, this concerned whether the participants were to share certain characteristics (i.e. achieving group homogeneity) or whether they were to be suitably diverse in these same attributes (i.e. achieving group heterogeneity). Whilst group homogeneity can be advantageous for developing deeper insights into a problem through constructing an integrated narrative based on shared experience, group heterogeneity introduces the opportunity for the topic to be explored within a broader, discursive context (Guerrero and Xicola, 2018).

Aligning with the Pragmatist methodological principles espoused in this thesis, the profile of target participants - and therefore the composition of the group - was defined according to the overall research objective and within the practical limitations of the research design. Therefore, to appropriately address RO1, professionals with diverse job-related characteristics, such as differing levels of BIM expertise, industry backgrounds, and exposure to upskilling activities, were sought to capture the underlying problem from multiple perspectives within a single forum. Although the difference in professional backgrounds could lead to conflicts in opinion and thus challenges in moderating the focus group – see Figure 4.2 – such observations and any emergent patterns would likely be representative of, or be of particular value to, the underlying key themes (Saunders, Lewis, and Thornhill, 2016). In addition, engaging with such a heterogeneous group was particularly suited to the exploratory nature of the present study, given the nascence of the

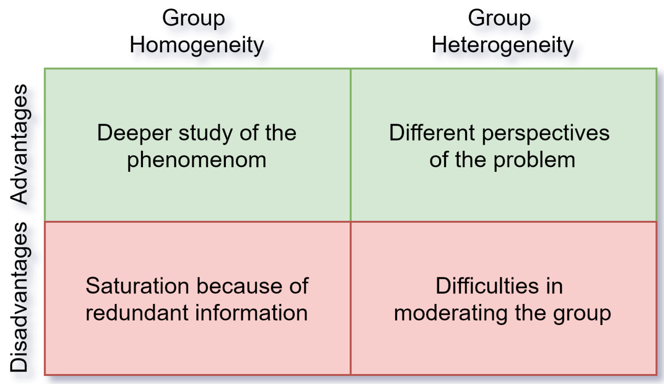


Figure 4.2 Advantages and disadvantages between heterogeneous and homogeneous sampling, adapted from Guerrero and Xicola (2018).

overall research domain and the gaps presented by the literature review.

However, an alternative approach, defined by Morgan (1997) as segmentation, was also considered in which participants were “segmented” into separate, internally homogeneous groups based on one of these professional characteristics, e.g. industry background. Observations and emerging themes could then be cross-analysed for inter-category comparison. However, Morgan (1997) notes that such complex segmentation designs would require the facilitation of multiple groups within each category of characteristic, thus requiring significantly more resource. In addition, as a social scientist, Morgan primarily advocates group homogeneity on the grounds of achieving free-flowing, productive discussions unhindered by more sensitive background characteristics, such as sex, race, age, and social class. As the characteristics of interest to the present study were generally less sensitive or inhibiting, they were therefore considered not to have a negative impact on an individual’s intent to contribute to the group’s discussion. Due to time constraints and given the negligible benefits gained from adopting such an approach, segmentation was not adopted in the present study.

4.2.2 Size and Number of Groups

There were two issues to consider when determining the study sample size: how many participants were to be included within a single group and how many focus groups were to be conducted for the study (Liamputtong, 2011). However, there is generally very little consensus or guidance on the appropriate sample size for focus groups or how many groups should be conducted to draw sufficient, robust observations. For example, Liamputtong (2011) illustrates how different scholars suggest a varying range of 'ideal group sizes', while Guest et al. (2017) found two thirds of the textbooks used in their review contained no guidance at all on the number of focus groups. However, where textbooks did include recommendations, the scope remained as equally as ambiguous; the range varied from as few as two focus groups to more than 40 (see Bryman, 2016, p.504 for examples of varying focus group sample sizes).

It is generally recommended to keep repeating the focus group activities until the point of data saturation is reached; that is, the point at which little to no novel information is being generated (Morgan, 1997; Liamputtong, 2011; Saunders, Lewis, and Thornhill, 2016). However, the point at which this is achieved is difficult to pre-empt which may have implications on the limited timeframe provided for the study. In addition, both Morgan (1997) and Bloor et al. (2001) stress the labour intensity required for recruiting participants, conducting the focus groups, and transcribing and analysing the data. The scholars therefore advocate pragmatically designing the sample size to reflect the overarching research plan within the boundaries set by practical limitations, with Morgan stating that "the goal is to do only as many groups as are required to provide a trustworthy answer to the research question due to the costs involved in conducting more groups" (Morgan, 1997, p.44).

This assertion is also supported by Saunders et al. (2016) who highlight that sample size is dependent on the nature of the participants, the subject, and the skill of the moderator rather than prescribing an exact figure. In addition, Bryman (2016) highlights how the volume of data from larger numbers of groups impacts upon the complexity of data analysis, which should be a consideration when in the planning stage of a focus group based study. Nevertheless, Bloor et al. (2001) contend that a sample size target should be established for the study using informed decisions which are appropriate to the context of the research. Ultimately, both sample size decisions for the present study were informed by the practical limitations surrounding participant recruitment and resource availability.

Typically, focus groups involve between four and twelve participants, with the supposed optimum consisting of between six and eight (Morgan, 1997; Bloor et al., 2001; Liamputtong, 2011; Saunders, Lewis, and Thornhill, 2016). This is a result of often-cited criticisms of group sizes at either end of the spectrum; small groups of participants with a low level of topic involvement may not stimulate effective discussion whereas larger groups may be difficult to moderate or allow enough time for adequate exploration of individual views and the interactive dialogue (Morgan, 1997; Bloor et al., 2001; Liamputtong, 2011). However, groups with fewer participants were desired for the present study for the following reasons:

- As the participants were professionals, time pressures had to be considered as to not impede too much on their working day. Therefore, fewer participants meant that the focus group could be shorter in duration whilst simultaneously ensuring all participants were given an equal opportunity to contribute.
- Secondly, their roles as professionals also meant it was likely that it would be difficult to align conflicting and busy schedules. It was therefore more practical to consider smaller groups based on the sheer availability of participants.
- The participants were considered to be advocates and/or users of BIM and therefore were highly involved in the topic. This reduced the risk of stagnating discussions due to the small number of group participants.

As recommended by Morgan (1997) and Bloor et al. (2001) it was intended to 'over-recruit' for each focus group by about 20% to account for last minute cancellations. Therefore, the study aimed to recruit six participants for each group, with an ideal attendance of at least four. Regarding the number of groups, Morgan (1997) suggests saturation is typically reached between three and five groups. However, Guest et al. (2017) found that more than 80% of themes were discoverable within two groups, which increased to 90% for between three and six. In any instance, Morgan cautions against using just one group as it would be impossible to identify to what extent group dynamics influenced the discussion. In addition, even as few as two groups allow for the researcher to assess the extent of saturation being achieved through how much the discussion differs from group to group. Therefore, the study aimed to recruit at least two focus groups as not only was this expected to yield sufficient data for addressing the research objective within the given timeframe, but it was most appropriate given the anticipated difficulty in recruiting participants.

4.2.3 Generation of the Theme Questions and Agenda

To guide the FGI session, an interview schedule was prepared. This provided a brief agenda for the participants ahead of the scheduled session and allowed the moderator to appropriately allocate time to each question. Each FGI session was divided into seven sections. Part One was a scripted briefing that introduced the study and its position within the overarching doctoral research, in addition to outlining the focus group protocols. Part Two was designed to allow each participant to introduce themselves and their professional backgrounds individually. It also included two short questions that asked about their experience with BIM and related upskilling activities.

Saunders et al. (2016) recommend that the questions used for focus group should follow a list of themes. Therefore, Parts Three to Six formed the main body of the interview, with each part representing a separate Theme Question, based on the themes identified in Table 4.1. Part Seven comprised a debriefing session which closed the focus group. This also provided the opportunity for any further points of discussion to be raised, following a summation by the moderator to ensure the participants were happy that the main outcomes were appropriately captured. The final agenda as structured around the four key themes is provided in Appendix C. The guiding questions are provided below:

1. **Theme 1:** What do you you think about the need to measure the rate of BIM adoption at an industry level?

2. **Theme 2:** What do you think are the factors that are most important for a person to consider themselves to have successfully adopted BIM?

3. **Theme 3:** What do you think of the current BIM upskilling (education and training) provision for industry practitioners?

4. **Theme 4:** What does the term "BIM competency" mean to you?

4.3 Practical Considerations

In accordance with Figure 4.1, the practical considerations surrounding Phase I of the research concern the selected sampling technique and the resulting profile of the participants, conducting the FGI sessions in a virtual environment, and outlining the FGI protocols, analysis strategy, and quality criteria.

4.3.1 Selecting the Participants

As the target participants were to be professionals in either an industry or upskilling capacity, it was impossible to construct an appropriate sampling frame from which cases could be selected at random. In addition, as an exploratory study, the intent was not to make inferences to a larger population but rather to understand the nuances enshrined within how a group of individuals interpret a particular issue using *a priori* theory (Bryman, 2016). This in turn enabled us to extract rich, detailed, qualitative information about the phenomenon which could only be practically achieved using a relatively small number of cases. Accordingly, the selection of the participants was conducted using non-probability, or non-random, sampling techniques.

Professionals with diverse job-related characteristics, such as differing levels of BIM expertise, industry backgrounds, and exposure to upskilling activities, were sought to capture the underlying problem from multiple perspectives within a single forum. Although the difference in professional backgrounds could lead to conflicts in opinion and thus challenges in moderating the focus group, such observations and any emergent patterns would likely be representative of, or be of value to, the underlying key themes . In addition, engaging with such a heterogeneous group was particularly suited to the exploratory nature of the present study, given the nascence of the overall research domain and the gaps presented by the literature review.

Self-selection sampling allows for potential participants to express interest in taking part in the research following a publicised call for help. This can be advantageous for exploratory research as Saunders et al. (2016) note that the voluntary nature of participant recruitment tends to result in participants coming forward who offer particularly strong feelings and opinions on the stated research topic. The present study employed the use of the online social media platforms, Twitter and LinkedIn, for advertising the research opportunity. The platforms also provided audience members with the facility to share the posts, which included a contact email address, within their own extensive networks. This allowed the study to become visible to potential participants not included within the researcher's own network.

Table 4.2 presents the demographic data concerning the participants on the next page. As outlined in the table, the decision was taken to conduct only two FGIs because of limitations on time and resources. This is because the act of gathering a group of experts together can be laborious in trying to coordinate busy schedules and organising agreeable times and locations. As demonstrated in Table 4.2, a sufficiently heterogeneous sample was obtained. Differences were noted across the years of experience, both in industry and working with BIM, in location within the UK, and in organization type and size. As the sample also consisted of representatives from across industry, policymaking bodies, and education and training providers, the sample was considered appropriate for providing a multilevel perspective on the identified themes.

Table 4.2 Demographic data for focus group participants

Code[1]	Experience (yrs)		Location[2]	Job Title	Organisation		Sector
	Ind.	BIM			Type	Size	
101	14	10	SC	Edinburgh BIM Lead	Design Consultancy	190	Industry
102	18	2	SC	Head of Public Partnerships & Future Workforce	Innovation Centre	18	Training Provider
103	13	13	EN	Digital Solutions Director	Engineering Consultancy	5,000	Industry
104	10	2.5	NI	AEC Software Consultant	BIM Consultancy	35	Industry
				MSc Student	University	*N/A*	Education
105	7	7	EN	Digital Construction Consultant	Engineering Consultancy	10,000+	Industry
				Guest Lecturer	University	*N/A*	Education
206	31	20+	SC	Digital Director	BIM & Digital Information Management Consultancy	1	Industry / Training Provider
207	20	7	EN	Head of BIM	Tier 1 Contractor	20,000	Industry
				Engagement Co-Lead	Alliance (Umbrella Organisation)	*N/A*	Policy
208	19	3	EN	Chartered Architectural Technologist	Architecture & Interior Design Practice	33	Industry
				Business Owner	Architectural Practice	1	Industry
				DEng Candidate	University	*N/A*	Education

[1] Codes are allocated based on which focus group the participant was in (No.–) and a sequential number based on the whole sample (–No.)

[2] EN = England, SC = Scotland, NI = Northern Ireland

4.3.2 Virtual Focus Groups

The concept of virtual focus groups is derived from adapting classical data collection activities using internet-assisted technologies. However, virtual focus groups present a different set of benefits and challenges than their in-person counterparts (Liamputtong, 2011). The advantages and disadvantages when compared to traditional face-to-face focus groups are provided in Table 4.3 (see next page). The table demonstrates that virtual FGIs are able to overcome some of the prevalent weaknesses faced by their face-to-face counterparts, particularly when considering the target audience for the present study. For example, the attributes relating to saved time and reduced travel were considered highly important when dealing with the recruitment of industry professionals. Moreover, as professionals who work in or advocate BIM adoption, the participants were considered to be comfortable with participation in an electronic medium (Guerrero and Xicola, 2018). Therefore, the FGIs were conducted virtually through video conferencing technology, namely the Cisco WebEx platform.

Table 4.3 Comparison of virtual vs. face-to-face focus groups, adapted from Guerrero and Xicola (2018).

Attribute	Virtual[1]	In-Person	Comments
Cost of the transcripts	High[2]	High	The same amounts of effort and resource would be required in either instance.
Proximity of the participants	Unlimited	Limited	Virtual FGIs remove the restriction on participant proximity / dispersion.
Need to travel	No	Yes	
Geographic range	Worldwide	Limited	
Length of the answers	Short	Long	The length of answers does not indicate quality, but it is important to note the difference in the level of answer detail.
Detail of the answers	Medium	High	
Cost of incentives	Low	High	Incentives would not be offered in either instance, but out-of-pocket expenses do not have to be considered for virtual FGIs.
Intragroup conflicts	Medium to High	Low	Differing points of view are encouraged. Participants tend to find it easier to express their views when not in person.
Ease of diagreeing	Medium to High	Low	
Freedom of expression	Medium to High	Low	
Technological dependence	High	Low	Virtual FGIs are only successful if the technology is working effectively. Effects should be made towards testing the tools prior to hosting the virtual FGIs.
Number of respondents	Medium to Low	Low	FGIs tend to have low response rates in general, but the flexibility offered by virtual FGIs makes it more attractive to potential participants.
Convenience for participants	Medium to High	Low	
Nonverbal input	High[2]	High	Enabled through video technology.
Vocal cues	High[2]	High	Enabled through audio technology.
Anonymity	Low[2]	Low	No written personal details are shared between the participants. Onscreen names are visible by first name only.
Security issues (participants' ID)	Secure[2]	Secure	

[1] The term "virtual" is synonymous with the concept of synchronous online FGIs, as stated within the original table.
[2] This classification was selected according to the fact that the virtual FGIs are audiovisual, rather than text-based. This delineation is not made in the original table, i.e. both audiovisual and text-based methods are considered under the term "virtual".

4.3.3 Focus Group Protocols

In accordance with the ethical considerations discussed in Section 3.4, soft copies of the consent form and the accompanying information sheet (refer to Appendix C for both documents) were provided to participants a week prior to the date of each study. Participants were required to provide written informed consent by returning the consent form containing a digital or scanned physical signature at any point prior to the commencement of the focus group. All forms for those who participated were collected on time and forms which were returned but subsequently not required due to last minute cancellations were destroyed. The terms and procedures outlined within the information sheet and consent form were also verbally reiterated as Part One of the agenda.

4.3.4 Transcription and Coding Strategy

The focus groups were recorded using the combined audio and video capturing facilities provided within the Cisco WebEx software. The moderator and assistant moderator took notes during both sessions to support the narrative in case some of the phrasing was unclear, and to also provide contextual comments where applicable. The audio files were then transcribed verbatim into word files. The text analysis tool, NVivo 9, was then selected to organise, store, and analyse the data in accordance with the coding scheme for Phase I of this study.

Saunders et al. (2016) suggest data is analysed using dimensions derived from a theoretical framework. However, since this was an exploratory study and a theoretical framework was not yet in place, the data analysis was guided by the four key themes introduced in Table 4.1. Therefore, a coding scheme was developed using an initial open analysis of the raw data and the background study for the themes. Adapted from the scheme devised by Gu and London (2010), the coding scheme uses five main categories: Sector, Context, Type, Content, and Keywords. An additional contextual category, Theme, was included to identify which theme the comment was responding to based on the agenda. Each category is briefly described below:

- The **Sector** category identifies the sector based on the respondent's demographics.

- The **Context** category marks the "circumstances under which a given segment of data has been discussed" (Gu and London, 2010, p.990).
- The **Type** category identifies the perceived purpose of the statement.
- The **Theme** category places the comment segment within one of the key themes within the agenda.
- The **Content** category provides a series of classifications drawn from the background literature and the clustering of data.
- The **Keywords** identify the emerging issues across all categories based on key phrases mentioned within the text. Keywords can also be prioritised through evaluation of its occurrence across the datasets.

See Gu and London (2010) for an extensive discussion on the adopted coding scheme, its categories, and its sub-categories. The coding scheme, using excerpts from the transcripts as examples, is presented in Table 4.4 on the next page.

Table 4.4 Focus group coding scheme examples, adapted from Gu and London (2010)

Comment Segment	Sector: Industry	Sector: Education	Sector: Training Provider	Sector: Policymaker	Context: Initiated	Context: Reply	Context: Follow-Up	Context: Chair	Type: Suggestion / Idea	Type: Concern	Type: Opinion / Viewpoint	Type: Observation	Type: Query	Type: Inform	Type: Strategy	Type: Wishlist	Theme: Adoption - Macro-Level	Theme: Adoption - Micro-Level	Theme: Upskilling - Macro-Level	Theme: Upskilling - Micro-Level	Content: Measurement	Content: Standards	Content: Training	Content: Core Body of Knowledge	Content: Competency - Experience	Content: Competency - Knowledge / Skills	Content: Barrier / Issue	Keywords
"...that's why people are so reluctant to fork out and that's because you don't know the quality of the information you're going to get."							✓				✓	✓								✓			✓				✓	reluctant; quality; information; "fork out"
"They've really focused on the documents and the ability to tick boxes from a document perspective..."							✓					✓								✓		✓	✓					documents; tick boxes
"If the people don't get it or don't want to engage then it will just fail..."							✓			✓		✓						✓		✓							✓	people; engage; fail
"We've got things like the NBS annual report that's quite good but it only hits a tiny, tiny sample of industry and roles and organisations"						✓				✓							✓				✓						✓	NBS; sample; roles; organisations
"It's pockets of excellence, not the whole company that's doing it, you know."					✓							✓						✓						✓	✓	✓	✓	"pockets of excellence";

The sector identification marks are removed to protect respondent privacy. Columns have been retained to demonstrate the full schema.

4.3.5 Quality Criteria

According to Creswell and Plano Clark (2007), the validity and reliability of the data and results should be clearly explained to ensure the research methodology enables sound data analysis and interpretation. However, whereas quantitative research relies on validity and reliability criteria for assessing quality, the positivist-aligned rigidity enshrined within these concepts makes them inappropriate for qualitative research where reality is socially constructed (Saunders, Lewis, and Thornhill, 2016). Therefore, after Guba and Lincoln (1994), Saunders et al. (2016) and Korstjens and Moser (2018) provide a series of quality criteria designed to assess the quality of a qualitative research design based on its trustworthiness. These are that the study is dependable, transferable, and credible.

Dependability, the interpretivist cousin to reliability, describes the ability to consistently report the research process and the recognition that the research context evolves (Saunders, Lewis, and Thornhill, 2016; Korstjens and Moser, 2018). As described by Jensen, dependability "cannot be completely understood *a priori* as a singular moment of time" (2008a, p.209). Furthermore, unlike quantitative studies, the small sample sizes associated with qualitative studies do not naturally lend themselves to producing results which can be generalised to a wider population. Instead, Guba and Lincoln (1994) advocates for qualitative research to focus on the ability to transfer the study's methods to another setting and achieve valuable results. For this reason, Jensen (2008b), Saunders et al. (2016) and Korstjens and Moser (2018) recommend that qualitative studies should provide a comprehensive description of the research, including its design, context, and interpretations. Jensen (2008b) also argues that the participants need to be linked to the context being studied to ensure it is being appropriately represented. Therefore, by comprehensively outlining the practical considerations in accordance with Figure 4.1, this chapter addresses these dependability and transferability concerns.

Credibility refers to ensuring that the views of the research participants are appropriately captured in a way that matches what the participants had intended (Saunders, Lewis, and Thornhill, 2016; Korstjens and Moser, 2018). Therefore, to ensure research credibility, the transcripts were sent back to the participants in a follow-up email for confirmation of the contents. No changes were requested, nor were any further comments added.

4.4 Exploratory Study Results

The two virtual focus group sessions were conducted on 12th and 15th April 2019 respectively. This section presents an analysis of the data collected during the two sessions by framing the findings against the four key themes.

4.4.1 Theme 1: Insufficient Adoption Rate Measures

The ability to measure the rate of macro-level adoption is generally viewed across sectors as a valuable activity within the context of the BIM discourse, e.g.:

Respondent 103: *"I think measuring is extremely important because you can't manage something unless you can measure it"*

However, the premise put forward by the literature review that current macro-level assessment tools are insufficient is validated by the findings of the focus groups. Notably, participants raised concerns around the ability to achieve an appropriate sample size, particularly when considering the scale and complexity of the AECO industry. Yet, as discussed in Section 2.2.2, one of the key advantages of commercial-based surveys is the ability to achieve generally larger sample sizes than academic-based efforts. Moreover, the samples were also criticized for only representing the views of those who are already interested in the subject, i.e. the samples achieved by surveys such as those conducted by the NBS exhibit strong self-selection or pro-adopter bias (Rogers, 2003). This therefore substantiates the complexity of being able to capture representative, real-world phenomena from a large, diverse industry.

Participants also raised concerns regarding how BIM is interpreted for the purposes of measuring rate of adoption. In particular, the perceived rate of adoption promoted by the NBS surveys was queried, with participants highlighting the subjectivity associated with the interpretation of the questions. For example, the adoption of the BIM could be interpreted as the adoption of the processes promoted by the PAS 1192 or ISO 19650 suites of standards, or the implementation of a technological application, such as Revit. This variable perception could be further exacerbated when considering the different disciplines involved within a single project setting, i.e. those who own the built asset will have a different experience of BIM to those who design it and to those who manage it. As one participant noted:

Respondent 105: *"You read the NBS report and it's difficult to say that's what you're going to experience in the real [...] world and that's the difficulty. One person's BIM is not another's."*

In summary, research, whether industry-based or academic, should clearly define how BIM adoption and use is measured, both in how questions are developed and in how the results are interpreted and reported. Moreover, when considering BIM as a process, this definition should consider, and attempt to capture, its systemic nature to prevent misinterpretation of BIM as one of its constituent parts, such as a single standard or tool.

4.4.2 Theme 2: Perceived BIM Adoption and Use

The focus group sessions identified that BIM adoption within industry is being primarily driven by the larger organisations. This is because larger organisations appear to have greater flexibility in allocating resources to implementation and upskilling activities than SMEs. These activities could include training staff or developing the relevant templates and protocols in accordance with the BIM standards. However, the industry-based participants highlighted that these activities equate to a loss of billable hours, which are a heightened concern for SMEs who deal with much smaller profit margins and therefore smaller levels of expendable resource. This is resulting in the perception that whilst adoption may be stagnating overall, the larger organisations are being able to continuously evolve and, as one participant noted, "*[move] onto the next big thing*", such as embracing augmented reality (AR) and processes mooted to represent Level 3 BIM.

However, there was a shared consensus among respondents that this is resulting in an increasing gap between those trying to adopt BIM and those who are already experienced. This is attributed, at least in part, to the perceived lack of support for those within industry who have not yet adopted BIM. Participants felt that although there has generally been an oversaturation in the promotion of BIM and digital innovation, there has been little grounded support for those new to BIM, i.e. the provision of accessible, step-by-step, practical support in implementing BIM into established workflows and business plans, particularly for SMEs. As the largest portion of the AECO sector, SME support and therefore buy-in is perceived as crucial:

Respondent 206: *"I think over the last decade, we've actually been focusing, or mostly the people talking are large industries, whereas we should actually be focusing on the micro-SME organisation because if we can get them on board, then everyone else will fall into place."*

Based on these assertions, cost was identified as a recurring issue and barrier to effective BIM diffusion. These concerns relate to the capital investment associated with internal implementation, e.g. initial training for existing staff, and to the procurement of relevant expertise to deliver BIM on projects, e.g. hiring new personnel for in-house expertise or outsourcing tasks to BIM consultants. However, investment in the people element of the people-process-technology triad is viewed as critical to BIM adoption success:

Respondent 206: *"With BIM, people, process, technology, people are the, like, the 99% element. If the people don't get it or don't want to engage then it will just fail and most time BIM falls down because of the people."*

4.4.3 Theme 3: Inconsistent Upskilling Provision

Discussions surrounding macro-level upskilling substantiate the claim that current upskilling provision from a macro-perspective is inconsistent. Crucially, participants highlighted that quality assurance of upskilling activities is difficult to assess, yet, the quality of upskilling material appears, anecdotally, to be highly variable across providers. Respondents also highlighted a reliance of upskilling courses to rely on technology-centric material, such as tool-based training and 3D modelling, rather than providing a holistic overview of the BIM process which encompasses the fundamentals, techniques, protocols, and philosophies.

Further reiterating cost as a barrier to adoption, the lack of quality assurance procedures creates a reticence in top management to invest time and money into staff upskilling, as suggested by the focus groups. Rather, money is seen as better spent on procuring external consultants, who can use third-party certification to demonstrate their capability, to satiate an immediate need. It could be argued that third-party BIM certification schemes aim to provide a standard against which practitioner knowledge, skill, and application are assessed and audited. However, as discussed in Section 2.3 and validated by the focus group sessions, there is no underlying standard, such as UKAS, governing the quality of these certification schemes to ensure consistency in assessment and message. Furthermore, most certification processes focus on the organisation's ability to adhere to a single standard rather than assessing actual practice. This has resulted in a reliance on assessing standardised document templates and protocols against an identified standard, rather than auditing how BIM is being implemented as a core value within the organisation and aligning with existing workflows. The issue of unstandardised certification schemes against recognised education standards can be demonstrated by the excerpt below:

Respondent 206: *"that was the main reason I went to go and do my Masters, because [...] I knew give it another five years, [the certificate] was just going to be a bit of paper and having that academic rigour behind you would actually be much more applicable to industry than actually going sitting something [by a certification scheme]."*

However, provision within higher education institutions is also considered to be highly varied, with a general consensus that universities generally do not have the expertise, nor the supporting structure, to deliver BIM education as part of their existing curricula. It is also suggested that the relationship between academia and industry is fractured, with little dialogue flowing between the sectors to facilitate knowledge and skill exchange. Yet, respondents agreed that knowledge of practical applications are critical to understanding what BIM competency is, which provides a business case for leveraging industry expertise in education. Generally, however, the core values relating to the BIM process need to be integrated into modules early to ensure graduates will be able to respond to the digital environment being implemented within industry. Furthermore, if aligned with industry standards, it is anticipated that by providing graduates with a recognised set of knowledge and skills prior to entry into the workforce, those already in industry will be motivated to upskill themselves:

Respondent 208: *"What that will do is push the guys in industry already to get [...] upskilled. They'll suddenly realise that "okay, I'm the only guy in the office who's still using a drawing board"."*

However, university courses may struggle to fundamentally adapt existing module structures, particularly considering the content and standards demanded by professional institutes for accredited courses. An alternative solution is to reach out to external initiatives to provide bolt-on material to an established module or curriculum. This could include initiatives such as school and college outreach programmes which aim to introduce students to BIM and careers in the wider built environment (e.g. Class of Your Own, 2020). However, participants agreed that securing constant, secure funding may be an issue for education providers to provide external content. This in turn affects the ability of the vendors and training providers to consistently invest in the continued development of programmes that can respond to the industry's evolving needs, such as the transition from PAS 1192 to ISO 19650. However, it is argued that other standards within industry also adapt and evolve to respond to industry challenges, particularly concerning environmental performance and building regulations. The challenge instead lies in achieving a consistent realignment across a highly varied, unstandardised upskilling model.

The focus group findings suggest that a standardised body of knowledge would promote a consistent level of basic digital construction literacy against which upskilling provision can be built and assessed. As previously highlighted, the focus groups acknowledged that any solution is unlikely to provide all upskilling required due to the inherent diversity and thus specialised needs of the AECO sector. Rather, such a body of knowledge would instead facilitate a fundamental understanding of what is basic knowledge and skills, versus what is specialist knowledge and skills, enabling course content to be tailored to the appropriate role or function. Additionally, respondents also expressed interest in having a central, accessible resource which, unlike current upskilling offerings, would provide an online showcase which sets out the practical steps needed for effective BIM adoption, assimilation, and implementation.

Nevertheless, the upskilling provision model, whether it is underpinned by a standardised framework or not, needs a change agent to drive the agenda. Because of the centralised push for BIM adoption, it is suggested that government bodies play this role to support industry achieve its vision as originally framed by the UK BIM Task Group. However, although organisations such as the UK BIM Alliance and the UK BIM Framework are the repositories for the standards and guidance, they are not currently set up to facilitate the conversation and resulting actions around upskilling without further government funding.

4.4.4 Theme 4: Competency and Assimilation

When considering how to define an individual's BIM competency, the participants agreed that any acquired knowledge and skills, whether through CPD points, education, or certification, should be qualified with experience of practical application. For example, as one participant remarked:

Respondent 208: *I'm trying to upskill myself but on a day-to-day basis, I don't actually get projects which I can actually demonstrate these skills on, so I definitely wouldn't say I was competent, but I have a fundamental knowledge of how.*

Nonetheless, the focus group findings reveal that there is a perceived gap between what individuals say they are able to deliver and what they are actually capable of delivering. The respondents offered two key perspectives on the issue. The first relates to the tendency of industry to inflate what they are doing, with one participant labelling this phenomena as "*Hollywood BIM*" and "*complete smoke and mirrors across the entire industry*". The second corroborates the argument presented in Section 2.2.3, in that the rate of adoption may be offset by an assimilation gap effect. An example of this effect is provided in the dialogue below:

Respondent 208: *What else is amazing is how many contractors have adopted a CDE and a naming convention but have no idea of how to actually manage that.*
Respondent 207: *Yes.*
Respondent 206: *Yep. See it every week.*
Respondent 208: *And they're screaming "we do BIM!" and I think what's happening then they're demonstrating the practical application on paper but if you'd actually scrutinised it you'd find lots of gaps and that hides your competition then.*
Respondent 207: *I completely agree. [...] we've got exactly that. We've set [the naming protocol and CDE solution] up and it all comes down to ownership of and people playing their part in the project team.*

The example provided highlights a misalignment between adoption activities (i.e. the procurement and embedding of a CDE solution) and actual use. It also highlights an example of a fundamental element of BIM which is applicable to multiple, if not all, parties within a project.

4.5 Concluding Remarks

This chapter has presented the practical considerations surrounding the data collection and analysis procedures of Phase I of the methodology. It has also presented and discussed the findings of the exploratory study, based on two focus group sessions held with various BIM stakeholders from the industry, education and training, and policymaking sectors. With regard to how the rate of BIM diffusion is measured, the participants agreed that the act of measurement is valuable, but also raised concerns about the current measures used by commerical-based surveys, such as the NBS National BIM Surveys. The key issues relate to sample size and representation, and the methodological transparency surrounding how BIM is defined and measured. With regard to perceived BIM adoption, the key issues are the cost-related barriers to effective implementation (particularly for

SMEs), and a perceived gap between those who are experienced with BIM and those who are starting out on their BIM journey. With regard to current upskilling provision, the focus group sessions highlighted a highly variable landscape of training, education, and certification offerings, with participants expressing concerns relating to the lack of quality assurance and a consistent underlying framework. Other key issues relate to a fractured relationship between academic and industry-based training providers, the lack of appropriate funding mechanisms for both receiving and delivering upskilling material, and the lack of a centralised change agent focusing on pushing a BIM upskilling agenda. With regard to competency and assimilation, participants indicated that there is a gap between to what extent people perceive themselves to have adopted BIM and to what extent they are actually delivering information on BIM projects, thereby corroborating the mooted existence of an assimilation gap effect.

In summary, the results of the focus groups were consistent with the emergent issues as identified by the literature review and has therefore empirically validated the response to Research Objective 1. Using these findings to frame the discussion, Chapter FIVE will examine the application of relevant theoretical models and frameworks for the purposes of developing the conceptual framework to underpin the present study.

CHAPTER FIVE

TOWARDS A THEORETICAL UNDERSTANDING OF BIM ADOPTION

This chapter presents the second and final part of the literature review. The exploratory phase of this research constructed a narrative that focused on the value of ubiquitous BIM adoption and its challenge to the existing upskilling model employed within the UK as a multifaceted, systemic construction innovation. Building on this premise, this chapter aims to explore the theoretical foundations of BIM diffusion and assimilation through the lens of Information Systems (IS) innovations research. By doing so, this chapter will address Research Objective 2.

Chapter FIVE begins by discussing the conceptual implications of approaching BIM adoption from a multi-level perspective and uses this dialogue to frame an overview of IS-based innovation theory as applied to BIM. The review then explores key theoretical models and discusses the strengths, potential contributions, and limitations of each. The chapter concludes by aligning the narrative constructed in Chapters TWO and FOUR with the conceptual discussions presented here and establishes the gaps in theoretical understanding to be addressed by the present study.

5.1 BIM AND IS INNOVATION THEORY

The remit of analysing BIM adoption is arguably broad; there are a number of relevant academic domains in which this area fits, such as implementation science, behavioural change theory, and change management practices. However, given the technological connotations inherently associated with BIM, scholars are beginning to frame the study of BIM adoption within an Information Systems (IS) context to aid the development of an appropriate theoretical understanding (e.g. Davies and Harty, 2013a; Bosch-Sijtsema et al., 2017; Song et al., 2017; Ahmed and Kassem, 2018; Dowsett and Harty, 2018;

Oesterreich and Teuteberg, 2019). These efforts respond to the calls of Merschbrock and Munkvold (2012) who strongly advocate the application of IS as a so-called ‘reference discipline’ from which elements can be drawn to inform the study of BIM. This view has since been echoed by BIM scholars, such as Hosseini et al. (2015) and Bosch et al. (2017). These principles have since been enshrined within the Unified BIM Adoption Taxonomy (Ahmed and Kassem, 2018) which exploits the well-established knowledge base within IS to mobilise constructs and ideas appropriate to BIM – see Section 2.1.3 for further discussion. Therefore, by approaching BIM adoption using IS research as a lens, the present study emphasises and contributes to the growing synergies between the two areas.

The extensive study of the adoption of IS-based innovations has converged on a core set of theoretical models and frameworks which have been comprehensively validated across a plethora of technological applications. By drawing on sociological and psychological backgrounds, these models seek explanation for adopter behaviour, acceptance, and continued use (Gallivan, 2001; Taherdoost, 2018). Prominent examples include the Diffusion of Innovations Theory (Rogers, 2003), the Theory of Reasoned Action (Fishbein and Ajzen, 1975), the Technology Acceptance Model (Davis, 1989), the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), and the IS Success Model (Delone and Mclean, 2003).

As a precursor to developing the UBAT, a systematic review conducted by Ahmed and Kassem (2018) demonstrated that 76% of the studies identified for their review had applied such IS-based theoretical standpoints to analyse the adoption process. However, the review also reinforced the emergent nature of this direction of BIM adoption research; using robust quality assessment criteria, only 34 papers were selected for review out of an initial 3110. Furthermore, the search strings used in the study were not limited to considering BIM only, but also included general construction-based innovation adoption studies. Taking this into consideration, only 19 of the 34 texts – or 56% - were related specifically to the adoption of BIM and only 13 of these – or 38% of the original 34 – applied one or a combination of the theoretical lenses identified.

Despite these low figures, the study by Ahmed and Kassem represents a departure point for the present study and acts as a frame of reference for developing an overview of relevant innovation adoption theories and models. Accordingly, Table 5.1 presents the studies identified, with those having been included in the previous study being highlighted. Those not related to BIM adoption were removed, as was one doctoral thesis. The remaining papers (*N*=15) were identified from the search strings employed in Section 2.1.2.

As illustrated in Table 5.1, these studies vary substantially in their theoretical approaches, oftentimes adapting and extending traditional models to better suit BIM as the adopted innovation. Although this does not represent an exhaustive list of applicable theories, the emergence of these theoretical perspectives as informed by prior literature provides a strong foundation on which to better understand the contributions of IS-based models and frameworks. An overview of the focus and methods used for each of the studies included in Table 5.1 is provided in Appendix B.

Table 5.1 Use of theoretical models and frameworks in BIM adoption studies

Key: 🟢 = Mentioned / Reviewed; 🟠 = Used As-Is; 🟣 = Extended / Adapted; 🔵 = Combined With; 🔴 = Used Constructs From

DOI = Diffusion of Innovations Theory; InT = Institutional Theory; ISSM = Information Systems Success Model; TTF = Task-Technology Fit; TAM = Technology Acceptance Model; TOE = Technology-Organisation-Environment framework; TPB = Theory of Planned Behaviour; TRA = Theory of Reasoned Action; UTAUT = Unified Theory of Acceptance and Use of Technology.

Study	**DOI**	**InT**	**ISSM**	**TTF**	**TAM**	**TAM2**	**TAM3**	**TOE**	**TPB**	**TRA**	**UTAUT**	**UTAUT2**	*Other*
Acquah & Oteng (2018)					🟠🟢	🟢	🟢						
Addy et al. (2018)											🟢	🟠🟢	
Ahuja et al. (2016)	🔴							🟣🟢					
Ayinla & Adamu (2018)	🔵🟢												🔵🟢
Bosch-Sijtsema et al. (2017)	🔴	🔴	🔴		🟢			🔵	🔵🟢				🔴
Cao et al. (2014b)		🟣🟢											
Cao et al. (2016)	🔵	🔵											
Davies & Harty (2013a)	🔴				🟢	🟢	🟢				🟠🟢		
Dowsett & Harty (2018)			🟠🟢										
Gholizadeh et al. (2018)	🟢												🟠🟢
Gledson & Greenwood (2017)	🟠												
Gurevich et al. (2017)				🔵	🔵	🟢	🟢						🔴🟢
Hilal et al. (2019)				🟢	🟢	🟢	🟢			🟢			
Hosseini et al. (2016)			🟢										
Howard et al. (2017)											🟣🟢		
Juan et al. (2017)					🔵🟢								🔵🟢
Kim et al. (2016)	🔵🟢				🔵🟢								
Lee & Yu (2016)					🟢	🟢	🟢						

Continued on next page

Table 5.1 – *Continued from previous page*

Study	**DOI**	**InT**	**ISSM**	**TTF**	**TAM**	**TAM2**	**TAM3**	**TOE**	**TPB**	**TRA**	**UTAUT**	**UTAUT2**	*Other*
Lee et al. (2017)			● (green), ● (blue)		● (green), ● (blue)								
Lee et al. (2015)			● (red)	● (green)	● (green), ● (red)	● (green)	● (green)		● (green)				● (red)
Merschbrock & Nordahl-Rolfsen (2016)					● (green), ● (orange)								
Qin et al. (2020)					● (green), ● (blue)	● (green)	● (green)	● (green), ● (blue)			● (green)	● (green)	
Samuelson & Björk (2013)	● (green)										● (green)		● (green)
Son et al. (2015)	● (red)				● (green), ● (purple)		● (red)				● (red)		
Song et al. (2017)	● (green)		● (green), ● (purple)		● (green)								
Wang et al. (2016)	● (red)							● (green), ● (purple)					
Wang & Song (2017)					● (red)								● (purple)
Xu et al. (2014)	● (green), ● (blue)				● (green), ● (blue)								

5.2 Considering the Micro-Macro Relation

When discussing the implications of a unified ontology, Chapter TWO introduced the concept of the so-called scales of investigation, which pertains to whether BIM adoption is studied at either the micro-, meso-, or macro-level. Understanding these levels of analysis is critical for constructing an appropriate theoretical lens through which to frame the study. However, the chapter also presented a case for considering the interactions between the various levels of analysis. For example, Section 2.2 highlighted how the diffusion dynamics at play within the UK's BIM agenda rely on the actions of organisations at the meso-level, which in turn are influenced by their absorptive capacity and the collective behaviour of the individuals at the micro-level.

Innovation adoption in itself relies on interactions between these levels of analysis rather than restricting study to one scale (Briscoe, Trewhitt, and Hutto, 2011; Tscherning, 2011). This is because innovation adoption is a multi-level concern, in that individuals drive the decision-making activities, whether for themselves or on behalf of a group, which in turn drives the relative success of its diffusion. See Figure 5.1 for a diagrammatic representation of the levels of analysis in IS research.

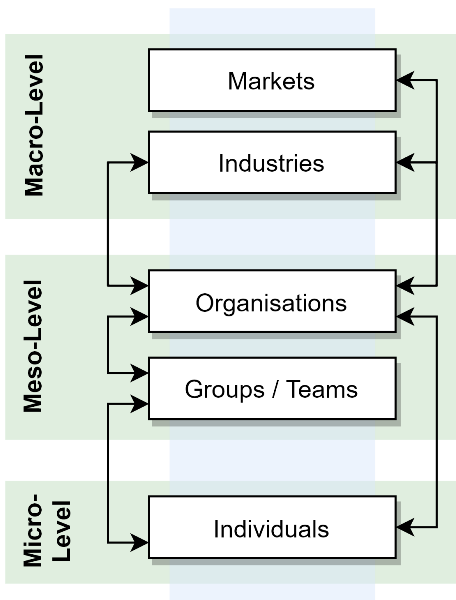


Figure 5.1 Multiple levels of analysis in IS research, adapted from Tscherning (2011)

Systemic innovations such as BIM, require consistent inter- and intra-level interactions between stakeholders to achieve effective utilisation. Yet, studies which straddle the micro-macro boundaries (i.e. multilevel research) beyond these incremental inter-level steps have traditionally been rare, resulting in any rich insights gained at one level not being considered at the other (Tscherning, 2011). However, understanding how micro-level behaviour influences macro-level phenomena, and vice versa, presents some theoretical challenges.

Within social sciences, in which innovation adoption research is grounded, the relationships between the constituents of a social system (i.e. the units at the micro-level) and wider social phenomena presents a so-called micro-macro problem (Coleman, 1986; Wiley, 1988) or divide (Briscoe, Trewhitt, and Hutto, 2011). Sociologist James Coleman defined this problem as "the process through which individual preferences become collective choices and individual actions become collective actions" (Coleman, 1986, p.1321). Our capacity to explain the micro-macro and macro-micro relationship therefore relies on the recognition that different levels of aggregation can hold relations with each other. According to Coleman's stylised 'bathtub' scheme as seen in Figure 5.2 individual actors within a group can influence the wider behaviour of the group and, conversely, groups can affect its members (Coleman, 1986; Raub, Buskens &, and Van Assen, 2011).

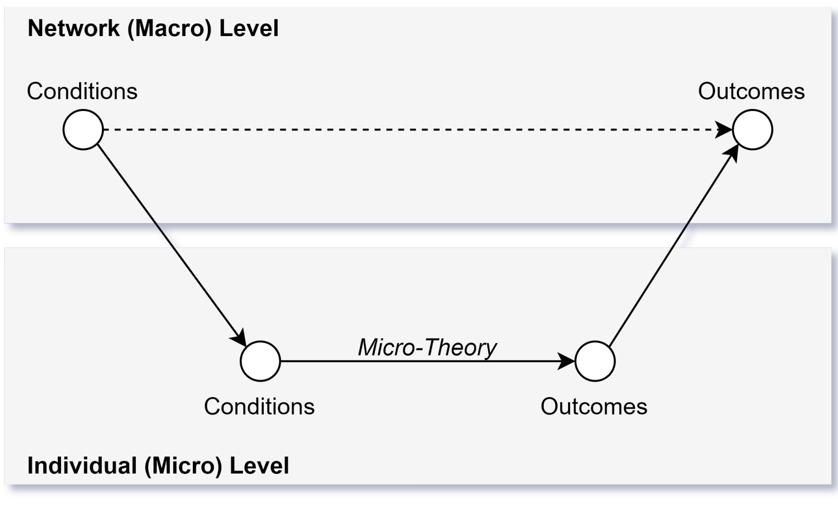


Figure 5.2 Coleman's multilevel 'bathtub' scheme, adapted from Raub et al. (2011)

Failure to acknowledge these relationships can result in the research being subject to either the atomistic fallacy[1] or the ecological fallacy[2], both of which fall under the umbrella of the micro-to-macro problem. In other words, the micro-macro problem describes firstly the tension arising from scaling micro-level models up to describe macro-level phenomena, thereby potentially exacerbating small variations. It then describes the limitations in aggregating data within a macro-level model and potentially obscuring phenomena better understood at the micro-level. This feeds into a wider sociological debate surrounding the doctrines of methodological holism and methodological individualism or reductionism (Coleman, 1986). The former describes ontologically viewing the world from a systems point of view, whereas the latter describes viewing these systems as the aggregate of its constituent parts.

Whilst this is a much larger issue than can be addressed by this thesis, it is important to be cognisant of the impacts this debate has on our ability to derive and apply theory within the context of the present research. This is because much of the theory surrounding general innovation adoption research has been derived from behavioural perspectives, thus concentrating on micro-theory (Figure 5.2). Yet, it is apparent that tensions arising from interactions between the various levels of analysis exist, particularly when considering the implementation of a systemic, coordinated innovation such as BIM.

Recent literature within the BIM adoption domain has started to recognise these inter-level tensions (e.g. Ahuja et al., 2016; Gholizadeh, Esmaeili, and Goodrum, 2018; Papadonikolaki, 2018; Wang et al., 2020). For example, a recent study by Troiani et al. (2020) investigated how Italy's macro-level BIM maturity influences BIM implementation at the micro-level, and found strong support for macro-driven standardisation. Additionally, Poirier et al. (2015) highlighted the existence of four distinct but embedded contexts influencing the BIM adoption and implementation process in SMEs: the industry context, the institutional context, the organisational context, and the project context.

To define the theoretical framework for the present study, the school of thought known

[1] The atomistic fallacy is defined by Diez Roux as "drawing inferences regarding variability across units defined at a higher level based on data collected for units at a lower level" (Diez Roux, 2004, p.588).

[2] The ecological fallacy is defined by Roux as "drawing inferences at the individual level [. . .] based on group level data"(Diez Roux, 2004, p.589).

as methodological individualism is followed. This describes the doctrine of understanding macro-phenomena as the result of aggregate units, whilst accounting for the influence of inter-level contextual factors on individual behaviour, i.e. society is viewed as a sum of social relationships (Coleman, 1986). Drawing also on IS adoption research, this study refers to the work of Tscherning (2011) to frame the discussions surrounding theory development based on inter-level interactions.

As shown in Figure 5.3, Tscherning's Multilevel Framework for Technology Adoption adapts Coleman's bathtub schematic to offer an explanation of IT adoption based on the interactions between the micro- and macro-levels (Tscherning, 2011). Although Tscherning acknowledges that the MFTA represents a simplification of reality, the model presents an opportunity to embrace a multilevel approach and by considering the impact of social network dynamics on individual adoption decisions, and vice versa.

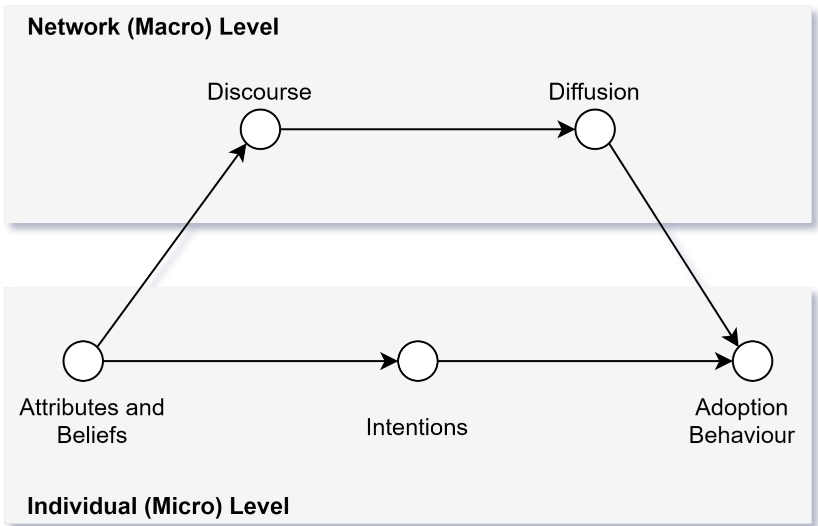


Figure 5.3 Multilevel Framework for Technology Adoption (MFTA), adapted from Tscherning (2011).

5.3 Theories and Frameworks

By leveraging understanding of how micro-constituents can interact with macro-phenomena with innovation adoption as a lens, this chapter has so far provided a springboard from which to consider BIM adoption from a theoretical perspective.This section introduces and discusses the previous applications of the core theories and frameworks as identified in extant BIM literature (see Table 5.1).

5.3.1 Diffusion of Innovations Theory

A plethora of theories have emerged as scholars seek to understand how, why, and at what rate an innovation spreads across a population. As a response to this ever-widening domain, Everett Rogers synthesised the extensive corpus of literature pertaining to the theoretical understanding of diffusion and presented a generic framework from which to shape basic concepts and terminology. The resulting Diffusion of Innovations (DOI) theory has since served as the foundation for a generalised understanding regarding how an innovation spreads throughout a population. The robustness of the theory can be illustrated through its prevalence in academic literature, as since the first edition was published in 1962, the text has been cited over 105,000 times and has spanned a vast array of disciplines and applications. At its core, the DOI posits that adoption of an innovation within a population is normally distributed over time (see Figure 5.4).

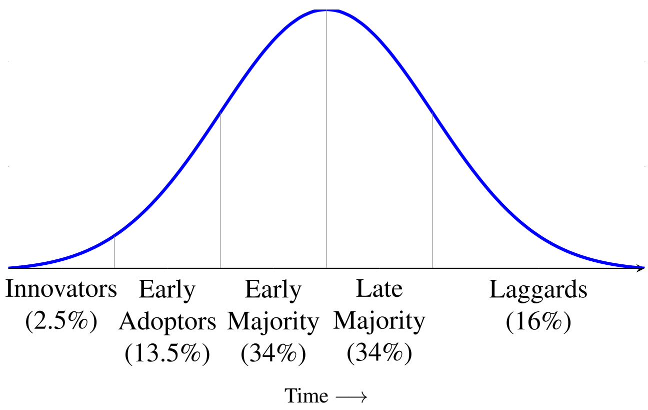


Figure 5.4 Adopter categorisation in the diffusion of innovations, adapted from Rogers (2003).

The DOI posits that the resulting cumulative percent curve, i.e. its rate of adoption, is determined by many interacting characteristics and factors. As illustrated in Figure 5.5, these include the five perceived attributes of innovations: their Relative Advantage, Compatibility, Complexity, Trialability, and Observability. These perceived attributes are theorised to determine as much as 49% to 87% of variance in the rate of adoption of innovations (Rogers, 2003).

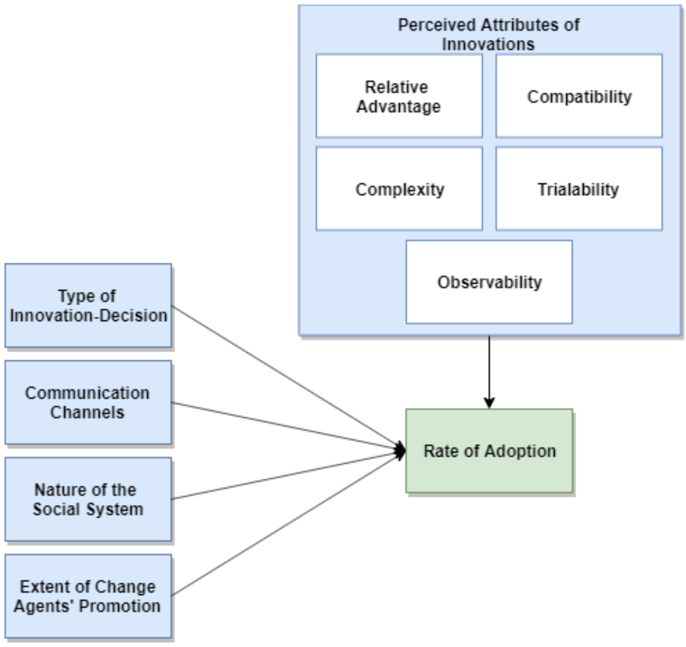


Figure 5.5 Factors affecting the rate of adoption of an innovation, adapted from Rogers (2003).

Further variance can be determined by the Type of Innovation-Decision, the network's Communication Channels, the Nature of the Social System, and the Extent of Change Agents' Promotion Effects, although to what extent each factor contributes to variance remains under-researched (Rogers, 2003). However, as a generalised theory pertaining to multiple perspectives of adoption, these factors can also be leveraged to explain adoption behaviour using any level of analysis and across any stage of adoption. Each of the constructs are described in Table 5.2.

Table 5.2 Overview of Diffusions of Innovations Theory

	Diffusion of Innovations (DOI) Theory
Level	Macro (Network / Industry), Meso (Organisation / Project), or Micro (Individual)
Author(s)	Rogers (2003)
Constructs	The **Rate of Adoption** is defined as "the relative speed with which an innovation is adopted by members of a social system" (Rogers, 2003, p.22). **Relative Advantage** is defined as "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 2003, p.212). **Compatibility** is the "degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters" (Rogers, 2003, p.224). **Trialability** is the "degree to which an innovation may be experimented with on a limited basis" (Rogers, 2003, p.243). **Observability** is the "degree to which the results of an innovation are visible to others" (Rogers, 2003, p.244). The **Type of Innovation-Decision** refers to whether the decision to adopt is optional, collective, or mandated by an authority. For example, Rogers posits that innovations are diffused more rapidly if the decision to adopt is optional among individuals when compared to organisation-level adoption. The **Communication Channels** through which the concept of the innovation is diffused is also theorised to have an influence on the rate of adoption. This concept proposes that the type of communication channels, which are generally identified as being interpersonal or via mass media, has to be suited to the innovation being diffused or it risks slower or stifled adoption rates. The **Nature of the Social System**, such as its social norms and the degree of interconnectedness supporting the communication structure within the system, will also influence the rate of adoption. If a change agent is employed to support innovation diffusion, the **Extent of Change Agents' Promotion Effects** will be an influencing factor, albeit with varying strength depending on the stage of diffusion (e.g. whether the innovation has reached a point of critical mass and therefore will continue to spread with little promotion from change agents).

DOI has already featured significantly in the present study by underpinning much of the discussion around BIM as an innovation. To summarise, DOI was used as a basis to understanding the nature of the AECO industry as a social system and the interactions present within it (Section 2.1.4). This research has also appraised BIM as an innovation using Rogers' definition and have attempted to further understanding national BIM strategies using governmental mandates within the context of the decision-to-adopt process (Section 2.2.1). Rogers' innovation adoption decision process was also referenced when discussing the role of the assimilation process (Section 2.2.3). Moreover, Rogers' adopter categorisation model (see Figure 5.4) is often used to describe the pattern of uptake, not only in academic publications but also within commercial and governmental reports (e.g. Fenby-Taylor et al., 2016), national surveys (e.g. NBS, 2020), and industry-based publications (e.g. Adams, 2016).

In their systematic literature review, Ahmed and Kassem (2018) demonstrate that DOI theory is one of the most popular IS-based theories discussed, adapted and applied in a BIM adoption setting. As noted by Cao et al. (2017), much of this work focuses on the technical perspective of BIM adoption by drawing on the theory's so-called perceived innovation characteristics - see Figure 5.5. This claim is supported by Table 5.1 in which many of these constructs are used to inform separate theory development, usually through integration with other theoretical models.

For example, this innovation attribute-driven approach has been adopted by Ahuja et al. (2016) who investigated Trialability, Compatibility, and Complexity as the Technology component within a TOE Framework setting. Wang, Liu and Wang (2016) adopted a similar perspective by introducing Observability and Comparative Advantage to their extended TOE Framework. Bosch et al. (2017) also approached the TOE framework in this manner, finding that Relative Advantage was the strongest driving force for BIM adoption among users. The approach of integrating DOI constructs with other theoretical models is also evident using TAM (Section 5.3.3), wherein the DOI's innovation characteristics assume the position of the External Variable construct in TAM, either fully (e.g. Kim, Park, and Chin, 2016) or in part (e.g. Xu, Feng, and Li, 2014).

However, assuming this attribute-focused approach limits our understanding of BIM adoption. This is because characteristics such as Trialability and Compatibility are inherently aligned to incremental innovations, where the act of adoption is framed as a dichotomous decision and around a single, bounded piece of technology. As highlighted in Section 2.1.4, such characteristics could be used to describe the adoption of individual

BIM components, such as in the case of 4D (time/scheduling) processes as demonstrated by Gledson and Greenwood (2016) or in terms of BIM functions, such as the approach taken by Gholizadeh et al. (2018).

In this regard, DOI considers innovation diffusion to be linear and does not consider adoption to be an evolving process, particularly when considering systemic or networked innovations such as BIM (Lyytinen and Damsgaard, 2001; Merschbrock and Munkvold, 2015). This assertion is supported by Shibeika and Harty, who state that "a simple, linear approach [...] or one based on the assumption of technology alone can bring about successful diffusion, may be likely to fail" (Shibeika and Harty, 2015, p.454). Therefore, DOI is limited in its scope in considering BIM as a systemic, modular innovation when assuming this solely technological perspective.

However, the DOI offers several other perspectives which can be exploited in a BIM context. For example, as briefly touched upon in Section 2.2.3, Rogers' Innovation-Decision Process (see Figure 5.6 on the next page) seeks to explain the process which is "an information-seeking and information-processing activity, where an individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation" (Rogers, 2003, p.172). Within the context of assimilation, the Innovation-Decision Process was discussed as one of several models through which to frame the act of procuring and internally diffusing modular innovations at a meso-level. In a BIM maturity context, Ayinla and Adamu (2018) integrated Rogers' adopter categorisation model (Figure 5.4), as applied within Singh and Holmstrom's own technology adoption model (2015), and the Bew-Richards maturity model. By doing so, the authors developed a preliminary tool for quantifying an organisation's so-called digital divide and its relationship with their assessed BIM maturity.

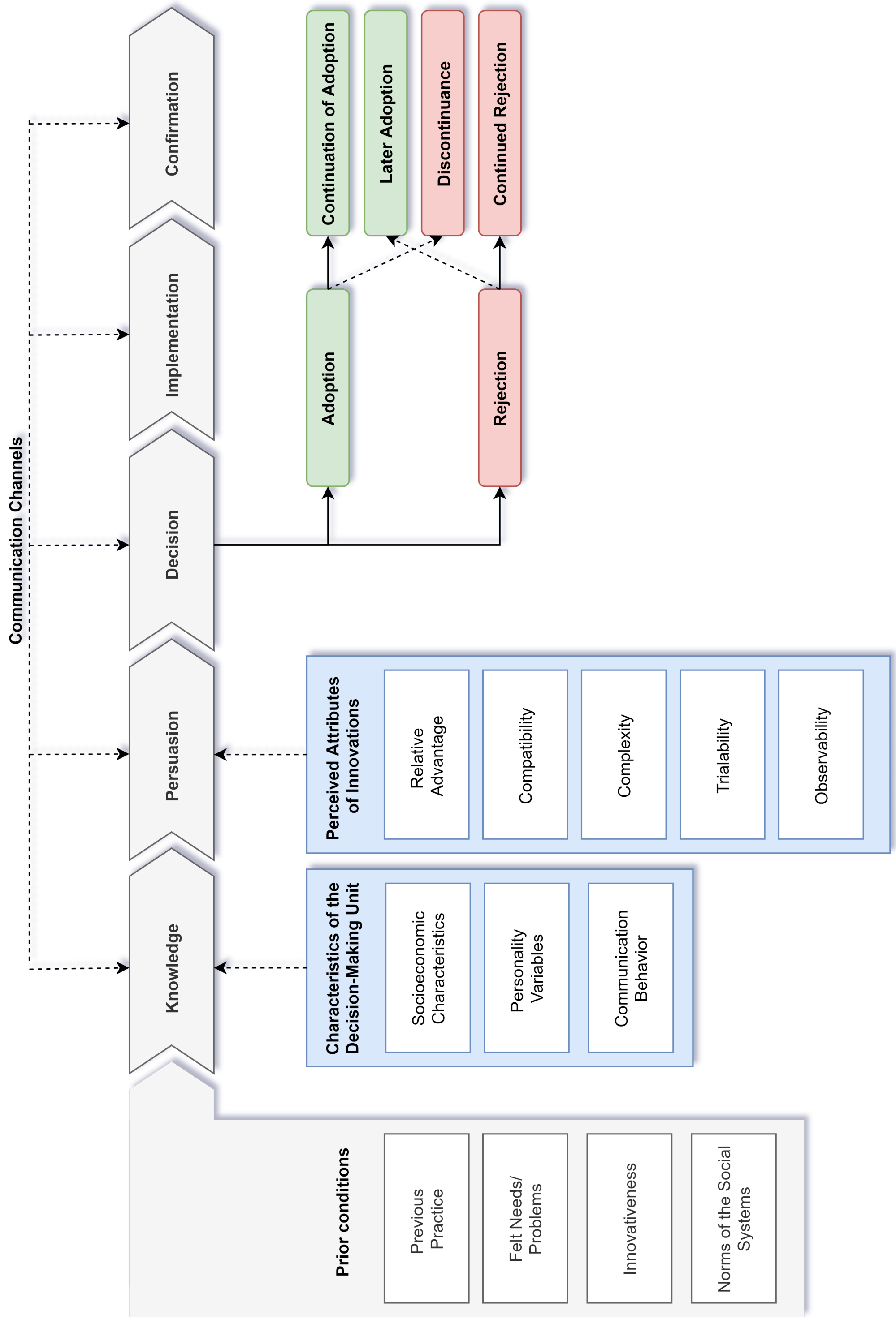


Figure 5.6 The Innovation-Decision Process, adapted from Rogers (2003).

5.3.2 Theory of Reasoned Action and Theory of Planned Behaviour

The Theory of Reasoned Action (TRA) is typically considered as one of the classic behavioural change theories, having informed much of modern theory surrounding innovation adoption using constructs rooted in social psychology (Fishbein and Ajzen, 1975). The TRA is exercised in a predictive context by drawing on the relationship between pre-existing characteristics of an individual and their execution of the behaviour under study. The well-researched model posits that behavioural action is explained by intentions to act, which are in turn explained by an individual's belief system surrounding the behaviour. A theory schematic of the TRA is provided in Figure 5.7.

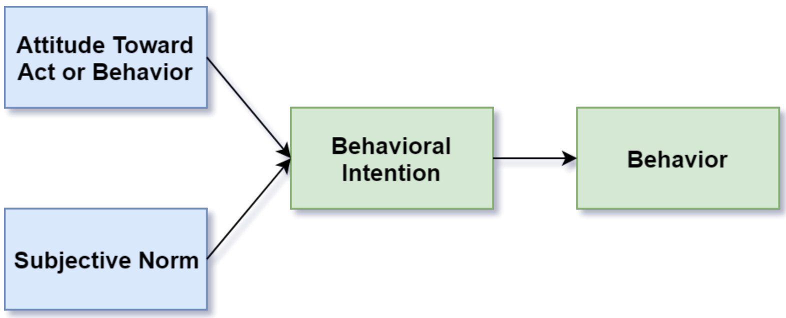


Figure 5.7 Theory of Reasoned Action (TRA), adapted from Fishbein and Ajzen (1975).

The Theory of Planned Behaviour (TPB) was proposed as an extension of the TRA to improve its predictive power (Ajzen, 1985; Ajzen, 1991). Like the TRA, the TPB posits that the individual's belief system forms intentions to act, which in turn form the behaviour of the individual. However, unlike its predecessor which presents two belief concepts, the TPB proposes that the belief system is comprised of three contributing factors. Rather, the concept of an individual's perceived volitional control was introduced to overcome criticisms of the TRA. Furthermore, the factors enshrined within the belief system are believed to act in combination: as a rule, if the factors comprising the belief system are all favourable, the more likely the individual's intentions to act will be. The TPB is illustrated in Figure 5.8.

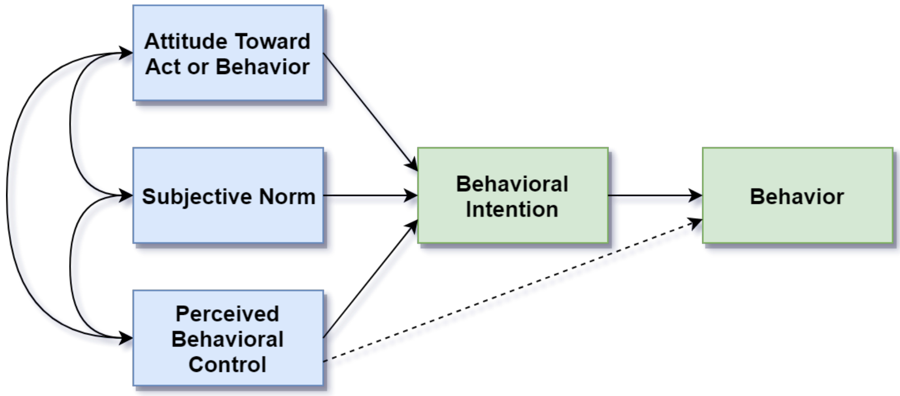


Figure 5.8 Theory of Planned Behaviour (TPB), adapted from Ajzen (1991).

Within a BIM adoption context, the TRA and TPB are generally introduced as historical precursors to IS-based innovation adoption theory, rather than directly applied or adapted (e.g. Davies and Harty, 2013a; Son, Lee, and Kim, 2015; Bosch-Sijtsema et al., 2017; Gurevich, Sacks, and Shrestha, 2017; Howard, Restrepo, and Chang, 2017; Poirier, Forgues, and Staub-French, 2017; Ahuja et al., 2020; Wang et al., 2020, etc.). The only identified exception to this rule is the study conducted by Ding et al. (2015), who explicitly identified the TRA as the basis of their theoretical structural equation model. However, the authors drew predominantly on the relationships between selected antecedent factors, such as motivation and management support, to explain the behavioural intention to use BIM. The study did not consider the relationship between behavioural intent and use, nor did it consider the influence of attitude or subjective norm as promoted by the TRA. Therefore, whilst the study highlighted the importance of considering enabling factors with regards to practitioners' intent to adopt BIM, it did not exploit the theorised relationships within TRA.

5.3.3 Technology Acceptance Model

The Technology Acceptance Model (TAM) is an adaption of the TRA and TPB which is specifically tailored to the field of IS-based innovation adoption and acceptance (Davis, 1985; Davis, 1989; Davis, Bagozzi, and Warshaw, 1989). The TAM affords the opportunity to explore and predict the factors that influence user attitudes and intentions towards using a technology or information system as the target behaviour. As with the TRA and TPB, the model consists of strong behavioural elements, but instead replaces the belief system measures with a single, exhaustive attitudinal measure and two fundamental, distinct technology acceptance measures. The TAM holds that the acceptance of technology is subject to the relationships between external factors and internal beliefs, enabling corrective feedback to be pursued if a particular technology is not accepted. Table 5.3 presents an overview of TAM and its constructs. Figure 5.9 sets these constructs out in a path model.

Table 5.3 Overview of the Technology Acceptance Model (TAM)

Technology Acceptance Model	
Level	Micro (Individual)
Author(s)	Davis (1985); Davis (1989); Davis, Bagozzi & Warshaw (Davis, Bagozzi, and Warshaw, 1989)
Constructs	Following TRA and TPB, the TAM theorises that **Actual System Use** is directly influenced by **Behavioural Intention to Use**, which is predicted by the individual's **Attitude Toward Using**. However, the TAM extends the premise of the TRA/TPB by proposing that **Perceived Usefulness** and **Perceived Ease of Use** mediate the relationship between **External Variables**, as antecedent factors, and the Attitude Toward Using. Furthermore, Perceived Ease of Use is said to positively influence Perceived Usefulness, which itself has a positive relationship with Behavioural Intention to Use. **Perceived Usefulness** is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p.320). **Perceived Ease of Use** is defined as "the degree to which a person believes that using a particular system would be free from effort" (Davis, 1989, p.320). **External Variables** are not defined by theory, but rather from contextual factors relevant to the technology under observation, e.g. system characteristics, development process, or training (Venkatesh and Davis, 2000).

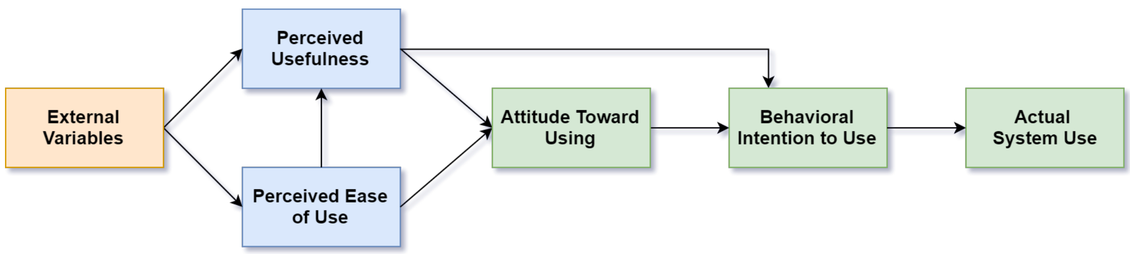


Figure 5.9 Technology Acceptance Model (TAM), adapted from Davis (1989).

The TAM is an extensively empirically validated tool designed to explain an individual's behaviour towards a technological innovation (Taylor and Todd, 1995). For this reason, the TAM has been applied in several capacities in BIM adoption research. As with the TRA and TPB, the TAM is oftentimes discussed as a precursor to more study-appropriate theory development (e.g. Poirier, Forgues, and Staub-French, 2017; Song et al., 2017; Wang and Song, 2017; Addy, Adinyira, and Ayarkwa, 2018; Papadonikolaki, 2018). However, the TAM has also been applied directly as a tool to explain the relationship between the perceived qualities and user acceptance of BIM. For example, Acquah and Oteng (Acquah and Oteng, 2018) utilised the TAM to understand BIM acceptance in the Ghanaian construction industry and found all hypotheses to be confirmed within the model. Merschbrock and Nordahl-Rolfsen (2016) used the TAM constructs to structure their case study which focussed BIM acceptance by on-site reinforcement workers.

Other studies have sought to exploit the External Variables construct to better explain the focal relationships within the TAM within the context of BIM. For example, Kim et al. (2016) drew on the DOI's perceived attributes of an innovation to act as the antecedent factors to the Perceived Usefulness and Perceived Ease of Use of BIM. Similarly, Qin et al. (2020) framed the contextual factors enshrined within the TOE framework (see Section 5.3.5) as the External Variables. Extending beyond the predominantly technological context, Son et al. (2015) theorised and confirmed that factors from across organisational, social, technical, and individual domains influence architects' perception of BIM, thereby influencing their behavioural intent to use it.

In a novel approach, Wang et al. (2020) adapted the TAM to explain Behavioural Resistance rather than Behavioural Intention. In doing so, the authors developed a series of factors drawn from micro- and meso-based contexts to act as antecedent constructs to Perceived Usefulness and Perceived Ease of Use, in addition to Perceived Distributive Equity drawn from equity theory. Both aforementioned studies demonstrate that multilevel contextual factors have varying degrees of influence on the individual perception-related constructs, thereby verifying that BIM adoption behaviour is indeed shaped by different levels of contextual factors in construction projects.

The TAM has also been used as the theoretical basis for the development of a so-called BIM Acceptance Model (BAM). Lee et al. (2015) developed this generalised framework which aims to explain BIM acceptance-related behaviour by drawing on the extensively verified relationships supported by traditional technology acceptance models. The BAM assumes a mutlilevel approach by theorising that organisational- and individual-level constructs influence the actor's perception of BIM, which in turn informs the Behavioural Intent of the individual and the Organisational Intent (see Figure 5.10). Therefore, the model posits that organisational- and indivdual-level acceptance is required for the effective utilisation of BIM. However, the BAM was criticised by Gurevich et al. (2017), who argued that the model only considers adoptions within the defined boundaries of organisations, thereby neglecting inter-organisational factors which are critical to systemic innovation diffusion. The BAM is therefore more suited to contextualised studies which seek to gain a richer insight into user acceptance within bounded organisations.

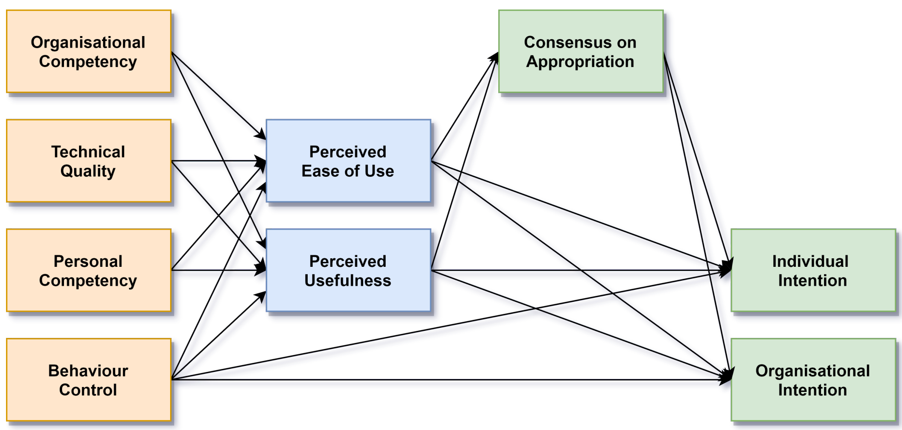


Figure 5.10 BIM Acceptance Model (BAM), adapted from Lee et al. (2015) and Lee & Yu (2016).

As with the Theory of Reasoned Action and the Theory of Planned Behaviour, the Technology Acceptance Model draws strongly on psychological constructs. As noted by Merschbrock and Nordahl-Rolfsen (2016), the criticisims surrounding the TAM focus on the strengths of these constructs and assumes that the innovation adopter is free to act without limitation. Yet, within the archetypal context in which BIM adoption is generally triggered, the decision tends to reside at the organisational level. Rather, micro-level adoption in this context can be framed as an authority-based secondary adoption process, in that adoption at the micro-level is contingent to adoption at the meso-level (Gallivan, 2001).

A later iteration of the TAM, the Technology Acceptance Model 2 (TAM2), extended the model to include constructs related to social influence (i.e. Subjective Norm, Voluntariness, and Image) and cognitive instrumental processes to better explain the perceived usefulness of the observed technology. However, within the context of BIM adoption research, TAM2 has not been investigated beyond recognition of its contribution to theoretical model development (e.g. Davies and Harty, 2013a; Takim, Harris, and Nawawi, 2013; Lee and Yu, 2016; Merschbrock and Nordahl-Rolfsen, 2016; Gurevich, Sacks, and Shrestha, 2017; Acquah and Oteng, 2018). Crucially, however, TAM2 introduced the concept of voluntariness and reintroduced the concept of Subjective Norm, which was removed from the TPB when TAM was first conceptualised. As stated by Gurevich et al. (2017), TAM2 places a greater emphasis on individual perceptions thereby reducing its applicability to any other context than the micro-level.

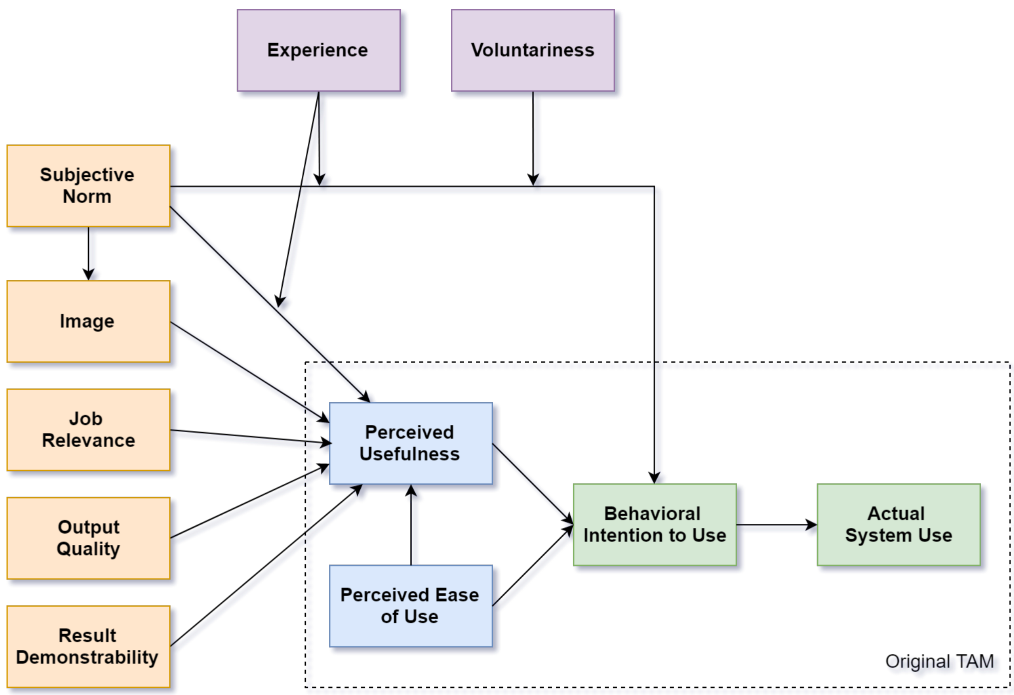


Figure 5.11 Technology Acceptance Model (TAM2), adapted from Davis (1989).

However, as noted in a review by Davies and Harty (2013a) and echoing the views of Venkatesh et al. (2003), TAM does not specify the level of abstraction of the studied technology. This has resulted in a broad range of IS-based systems being studied through the lens of the TAM which may not necessarily be appropriate. Instead, TAM tends to be applied to discrete, simple applications such as incremental innovations, such as mobile applications for BIM-enabled tools (Hong et al., 2019). Qin et al. (2020) also noted its neglect of social impact factors and also criticised the lack of consistent criteria when selecting measures for the External Variables construct.

5.3.4 Unified Theory of Acceptance and Use of Technology

The UTAUT was developed by Venkatesh (2003) as a comprehensive attempt to explain technology adoption and its relationship with user behaviour by drawing from existing theories and acceptance models, such as TAM, DOI, TRA, and TPB. Table 5.4 presents an overview of UTAUT and its constructs, whilst Figure 5.12 sets out diagrammatic relationships between the constructs.

Table 5.4 Overview of the Unified Theory of Acceptance and Use of Technology

Unified Theory of Acceptance and Use of Technology (UTAUT)	
Level	Micro (Individual)
Author(s)	Venkatesh et al. (2003)
Constructs	The UTAUT proposes there are four independent factors. **Performance Expectancy, Effort Expectancy**, and **Social Influence** are said to affect an individual's **Behavioural Intention**, whereas **Facilitating Conditions** impact on the individual's actual **Use Behaviour**. As posited in earlier theories, Behavioural Intention directly determines Use Behaviour. The relationships between the independent and dependent factors are moderated by **Gender, Age, Experience**, and **Voluntariness of Use**. **Performance Expectancy** is defined as "the degree to which an individual believes that using the system will help him or her to attain gains in job performance" (Venkatesh et al., 2003, p.447). **Effort Expectancy** is defined as "the degree of ease associated with the use of the system" (Venkatesh et al., 2003, p.450). **Social Influence** is defined as "the degree to which an individual perceives that important others believes he or she should use the new system" (Venkatesh et al., 2003, p.451). **Facilitating Conditions** are defined as "the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system" (Venkatesh et al., 2003, p.453).

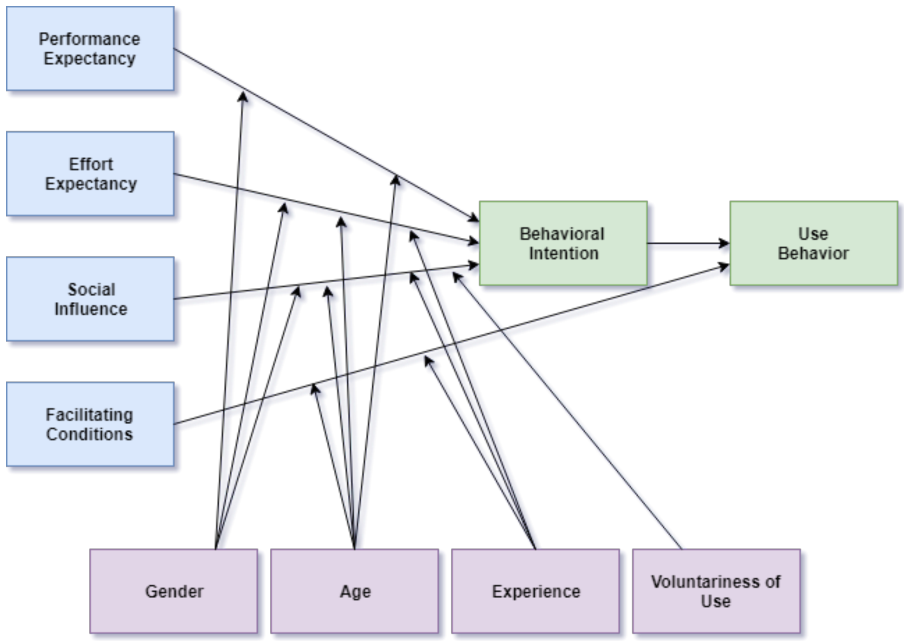


Figure 5.12 Unified Theory of Acceptance and Use of Technology. Adapted from Venkatesh (2003).

By collating key elements from these theories, Venkatesh postulated that UTAUT could be used to compensate for the weaknesses enshrined within them when applied in individual instances. BIM adoption studies using an iteration of the UTAUT include Howard et al. (2017), Addy et al. (2018), and Hilal et al. (2019). The most prominent example of the UTAUT being applied "as is" in BIM adoption research is the study conducted by Howard et al. (2017). As noted by the authors, the UTAUT provides an opportunity to consider BIM adoption at the micro-level, whereas a significant portion of BIM adoption literature considers the issue at the aggregate level. Whilst the core of the UTAUT remained the same, the model was adapted to suit the BIM context. Most notably, the authors removed gender and age as moderators and retained experience and voluntariness of use. These moderators were considered more appropriate for an innovation which is to be used solely within a professional rather than a personal capacity. Furthermore, the model also included an additional independent construct, Attitude, as an attempt to capture the individual's perception of BIM use within mandatory versus voluntary settings.

Other variations of the UTAUT have also been applied in BIM adoption research. Addy et al. (2018) used the UTAUT2 to frame their study of BIM adoption by quantity surveyors in Ghana. Expanding on the UTUAT, the UTAUT2 includes three further constructs:

Hedonic Motivation, Price value, and Habit. However, out of these new constructs, only Hedonic Motivation was found to have an impact on Behavioural Intention. Hilal et al. (2019) integrated the UTAUT with the TTF model (see Section 5.3.6) to investigate adoption within the Australian Facilities Management (FM) sector. To do so, the authors replaced the dependent variables from both models with a single construct pertaining to measure "BIM Adoption for FM". However, as a conceptual study, no empirical data was collected to test the model.

5.3.5 TECHNOLOGY-ORGANISATION-ENVIRONMENT

The recognition of the symbiotic relationships between different levels of contextual factors has been recognised in theory outside the technology acceptance domain. The most prominent example is the Technology-Organisation-Environment framework which is an organisational-level theory that considers and explains an organisation's process in adopting and implementing technological innovations. The framework describes how external influences, regardless of whether they act in a positive or negative manner, impact on the organisation's decision-making behaviour. As illustrated in Figure 5.13, the TOE Framework posits that the decision-making process is influenced by three interrelating drivers: the technological context, the organisational context, and the environmental context. These drivers are described in Table 5.5.

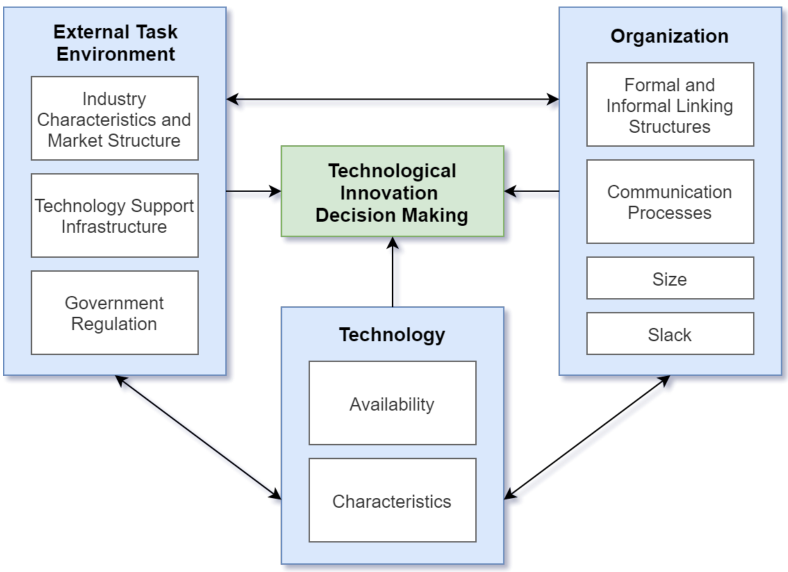


Figure 5.13 Technology-Organisation-Environment (TOE), adapted from Baker (2012).

Table 5.5 Overview of Technology-Organisation-Environment

Technology-Organisation-Environment Framework	
Level	Meso (Organisation)
Author(s)	DePietro, Wiarda & Fleischer (1990)
Constructs	The **Technological Context** considers the impact of all technologies relevant to the organisation, whether existing or to be procured in the future, on its decision-making processes surrounding the adoption of innovations. Factors posited to sit within the technological context include the availability and characteristics of these technologies. The **Organisational Context** refers to the characteristics and resources of the firm which are theorised to influence adoption-related decision-making activities. Relevant factors include organisation size and structure (e.g. degree of centralisation and/or intra- and inter-organisational links), amount of slack resources, and communication processes. The **Environmental Context** represents macro-level factors which are theorised to impact on individual organisation decision-making processes. The TOE Framework posits such factors include industry-level characteristics (e.g. market structure, industry size, and inherent competitiveness), the technology support infrastructure (e.g. the degree of external support by service providers), and Government regulation.

Within BIM adoption research, Song et al. (2016) conceptually expanded the TOE framework to include two further domains: risk, which focuses on the technical and legal risks of BIM adoption, and cost, which focuses on the business case based upon capital expenditure (e.g. hardware, software, and training costs) and the expected benefits (i.e. ROI). Similarly, Qin et al. (2020) introduced an Economic factor as the fourth dimension when considering the TOE factors as the External Variables within their integrated TAM-TOE model.

The TOE framework offers an opportunity to consider multiple interacting contextual factors on BIM adoption behaviour. As noted by Ahuja et al. (2020), the inclusion of the environmental context provides the TOE framework with the ability to better understand intra-organisation innovation diffusion. As has been seen with applications of the TAM, constructs pertaining to the perceived attributes of innovations were used to represent the technological context, namely complexity, compatibility, and trialability.

Despite this, the TOE framework "as is" has traditionally had relatively little empirical validation in BIM adoption research. However, in some studies, variables have been found to naturally group together into dimensions that can be aligned with the TOE framework factors. For example, Xu et al. (2014) grouped a series of factors derived from their integrated TAM-DOI model into Technology and Organisational drivers, in addition to a third Attitude dimension. Similarly, Ngowtanasawan (2017) grouped technology-based factors into a "BIM Characteristics" driver, organisation-based factors into a "Firm Characteristics" driver, and environmental-based factors into an "Environment Characteristics" driver.

5.3.6 Task-Technology Fit

As illustrated in Table 5.1, the Task-Technology Fit (TTF) theory is one of the lesser used models for explaining BIM adoption behaviours. However, the TTF theory has had a significant influence on IS-based theory development, particularly with regards to understanding how antecedent factors influence a use behaviour, which in turn influence utilisation and performance outcomes. The TTF theory predominantly considers the relationships between the antecedents to actual technological innovation utilisation, and the impact of its use on an individual's performance. A schematic of the theory is provided in Figure 5.14.

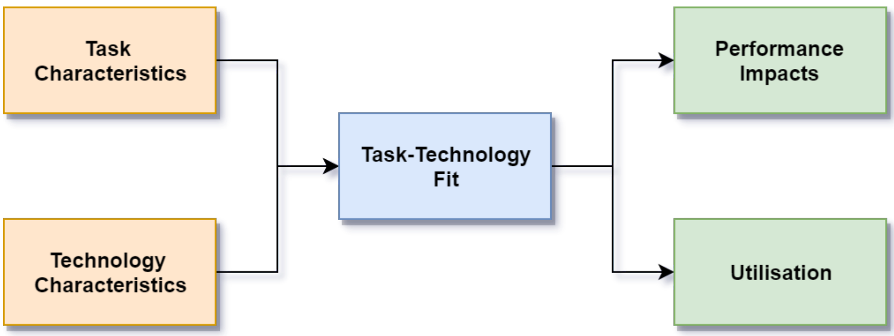


Figure 5.14 Task-Technology Fit Theory (TTF), adapted from Goodhue and Thompson (1995).

The TTF posits that the capabilities of the innovation will positively impact use and individual performance, if aligned with the tasks to be undertaken. This situates the theory as an effective diagnostic tool, considering its focus on adoption consequences and post-usage behaviour. Therefore, unlike constructs employed in previous theory which are generally transposable and self-contained, the constructs described in Table 5.6 specifically contextualise innovation use to suit the technology-task relationship.

Table 5.6 Overview of the Task-Technology Fit Model

Task-Technology Fit (TTF)	
Level	Micro (Individual), Meso (Organisational)
Author(s)	Goodhue (1995); Goodhue & Thompson (1995)
Constructs	The TTF theory holds that the **Task Characteristics**, such as task variety, difficulty, and interdependence, and **Technology Characteristics**, such as hardware availability and ease of assistance, form the antecedent factors to a **Task-Technology Fit** measure, which in turn influences Performance Impacts and the actual Utilisation of the technology. **Task-Technology Fit** is defined as "the degree to which a technology assists an individual in performing his or her portfolio of tasks" (Goodhue, 1995, p.216). **Performance Impacts** refer to "the accomplishment of a portfolio of tasks by an individual" (Goodhue, 1995, p.218). **Utilisation** is described in the TTF context as "the behavio[u]r of employing the technology in completing tasks" (Goodhue, 1995, p.218).

In the context of BIM adoptiion, Gurevich, Sacks and Shrestha (2017) draw on TAM and the TTF model to develop their so-called 'BIM adoption impact map'. The authors argue that the TTF model presents an opportunity to approach innovation adoption from a change management perspective, insofar as the organisation implements the change which in turn governs the environmental characteristics that influence an individual's use and acceptance of the innovation. With the context of BIM adoption, Gurevich, Sacks and Shrestha (2017) highlight the parallels between the TTF's consideration of the task, technology, and individual characteristics, and the process, technology, and people aspects which comprise the BIM ethos. The core tenet of the TTF is that an optimal configuration of these characteristics will enable users to complete their tasks using the innovation in a manner than delivers the greatest net benefit. To this end, the TTF model is particularly suited to considering BIM adoption within an organisational setting and places strong emphasis on organisational leadership in driving BIM adoption.

However, the existing TTF model is not compatible with the study of BIM adoption from a micro-perspective. More precisely, it is better suited to considering individuals' acceptance of incremental technology-based innovations, which is particularly true of the model's TTF construct. As a measure, the use of TTF could generate rich insights into the compatibility of individual BIM-enabled software tools with regards to ability to complete specific work activities in a manner much like the compatibility construct proffered by Rogers (2003). This approach was employed by Lee, Yu and Jeong (2015) who considered compatibility as a factor of technology quality within their research model. However, this perspective prioritises tool functionality over the nuances of the overarching BIM process, which makes the TTF construct, and by extension the TTF model, unsuitable as is for considering systemic innovations such as BIM.

5.3.7 Information Systems Success Model

IS adoption theories are predominantly focused on explaining the processes and factors which underpin the decision to adopt an innovation. However, this generally neglects the behaviours which occur following the decision to adopt the innovation. This is, in part, because the consequences of adoption are difficult to study and to generalise to a wider population (Rogers, 2003). Nonetheless, Rogers' Decision Innovation Process (Figure 5.6) posits that the decision-making unit has freedom to continue or discontinue use of the innovation based upon their own perceptions of the innovation's attributes. This suggests that the consequences of innovation adoption, and by extension whether its adoption is successful, are integral to stimulating and sustaining the innovation's diffusion curve by influencing the individual actor's continuance intention to use.

However, the measurement of IS Success in studies has been found to be highly varied, with most studies employing one-dimensional measures (Petter, DeLone, and Mclean, 2008). Oftentimes, these are borrowed from established IS theories, such as Perceived Ease of Use and Perceived Usefulness from technology-acceptance based models. Although these factors are extensively used and validated in IS studies, this has led to an inconsistent interpretation of the IS Success construct. To bridge this gap, William DeLone and Ephraim Mclean published the IS Success Model (ISSM) to overcome these issues and to synthesise the extensive corpus of work into a more comprehensive body of knowledge. Since its initial publication in 1992, the development of the ISSM has continued to be a cornerstone for the exploration and understanding of adoption consequences (Delone and Mclean, 2003; Petter, DeLone, and Mclean, 2008). The model primarily sets out a taxonomy for IS Success, which classifies its measures into six interrelated dimensions. These dimensions and a brief overview of the ISSM are presented in Table 5.7.

Table 5.7 Overview of the IS Success Model

Information Systems Success Model	
Level	Micro (Individual), Meso (Organisation / Project)
Author(s)	DeLone & McLean (1992); DeLone & McLean (2003)
Constructs	DeLone and McLean situate the Net Benefits factor in a cyclical relationship, highlighting the role it plays in stimulating further use. **Information Quality** is captured using completeness, ease of understanding, personalisation, relevance, and security as determinants. **System Quality:** "the desired characteristics of the information system itself which produces the information" (DeLone and Mclean, 1992, p.62), such as assurance, empathy, and responsiveness (Delone and Mclean, 2003). **Service Quality:** "the overall support delivered by the service provider" (Delone and Mclean, 2003, p.25) **Net Benefits** is the grouping of all relevant impact measures into one single category.

The ISSM is therefore a multidimensional instrument designed to capture, measure, and explain IS success and continued use. Figure 5.15 sets out the original theory schematic.

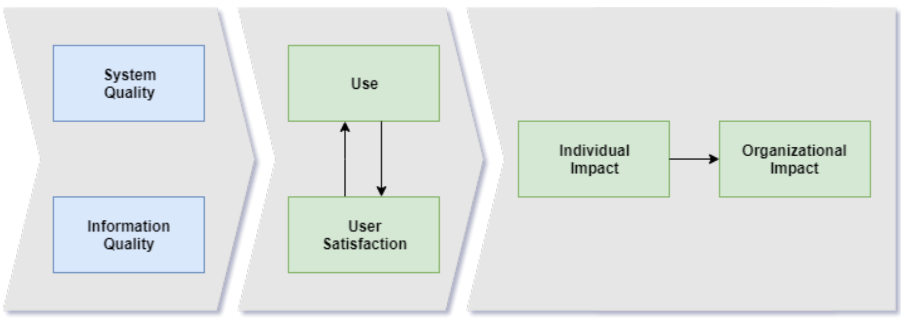


Figure 5.15 Original IS Success Model, adapted from DeLone and Mclean(1992).

Following several efforts by other researchers to extend and validate the original model, DeLone and Mclean proposed an updated model to respond to these criticisms and appraisals in an e-commerce context (Delone and Mclean, 2003). As set out in Figure 5.16, the updated ISSM presents a series of causal relationships between six interrelated dimensions, which, if the technology is satisfactorily adopted and in use, operates in a cyclical fashion.

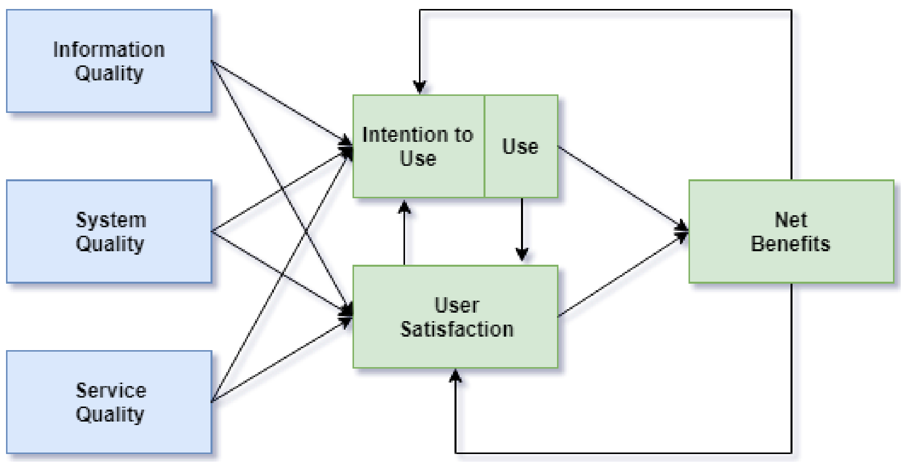


Figure 5.16 Updated IS Success Model, adapted from DeLone and Mclean(2003).

As noted by Lee and Yu (2012), studies in construction are starting to embrace IS Success measures as researchers seek to understand the nuances of IS tool adoption in the sector, such as employing web-based project management systems. As illustrated in Table 5.1, this can also start to be seen in BIM adoption studies, as scholars use and adapt the ISSM dimensions to develop a deeper understanding of BIM adoption in various contexts. For example, Dowsett and Harty (2018) use the ISSM constructs as a thematic map to identify the information use benefits associated with BIM implementation in two large scale projects.

Drawing on ISSM and TAM, Lee and Yu (2017) explored the relationship between BIM Acceptance and BIM Success. The authors define BIM Success as “an improvement in individual performance and organizational performance gained by integration management of required information throughout the lifecycle of a construction project” (Lee and Yu, 2017, pp.556-557). This definition is reminiscent of the original ISSM, in which individual and organisational impacts are distinct but related outcomes. The study found that to realise the various facets of BIM Success, organisations need to accept and embrace the value of BIM by continuing to invest in a supportive infrastructure at both the micro- and meso-levels.

5.3.8 INSTITUTIONAL THEORY

Institutional Theory (InT) presents a tool through which to understand social behaviour as established by the structures and processes enshrined within an institutional environment. The concept of an institution expands upon our understanding of single, bounded organisations. Rather, Scott (2014) defined the concept of institutions as comprising "regulative, normative, and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life" (2014, p.56). These three elements are set out as the core pillars to InT in Figure 5.17.

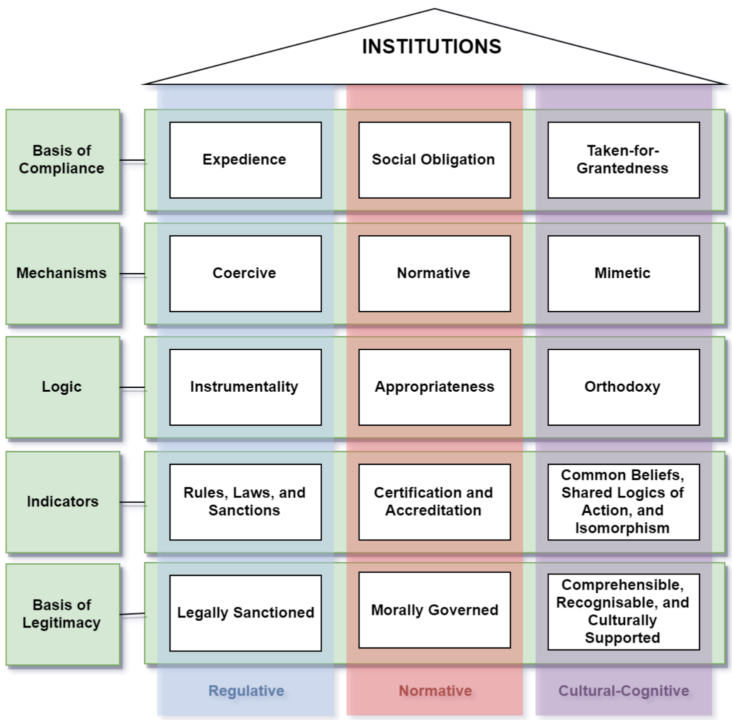


Figure 5.17 Institutional Theory: the three pillars of institutions, adapted from Scott (2014).

Institutions, therefore, can also concern wider, organised networks, such as integrated supply chains and construction projects, or even concepts such as 2D paper-based working (Babič and Rebolj, 2016). InT seeks to explain how change occurs within an institutional setting by drawing on the enablers and barriers interwoven into their structures and isomorphic processes. In an innovation context, the concept of change refers to the perceived ease of embracing and effectively diffusing innovations. Table 5.8 presents an overview of InT and its systems.

Table 5.8 Overview of Institutional Theory

Institutional Theory	
Level	Meso (Organisation/Project)
Author(s)	DiMaggio & Powell (1983); Scott (2014)
Constructs	Within the multifaceted definition of institutions, three distinctive but mutually reinforcing models, or pillars, supporting the institutions emerge: **Regulative Systems** which promote explicit regulatory processes, such as rule-setting and inspection, as tools to influence change within an institution. **Normative Systems** which emphasise the roles of values and norms to introduce a "prescriptive, evaluative, and obligatory dimension into social life" (Scott, 2014, p.64). **Cultural-Cognitive Systems** which thrive on socially constructed frameworks set within and shaped by an external cultural system. Although rarely empirically distinct, each pillar is characterised by several discrete dimensions. These are differentiated by their underpinning philosophical assumptions surrounding the nature of social reality. With regards to institutional change, these dimensions include: • The basis of an institution's **compliance** to change, or how change is driven. • The institutional isomorphic mechanisms, which govern how conformation to change is managed and influenced by external actors. • The empirical **indicators**, which are applied as tools to define the institutional logic employed to justify change. • The **legitimacy** of the institution's change behaviour, which reflects its "perceived consonance with relevant rules and laws or normative values, or alignment with cultural-cognitive frameworks" (Scott, 2014, p.72).

Unlike the other theoretical frameworks explored in this chapter, InT does not automatically lend itself to being structured as an analytical path model. However, InT has been noted to be one of the most frequently used theories from which to draw constructs within BIM adoption research (Ahmed and Kassem, 2018). Yet, Turk (2016) believe InT's application to BIM adoption research is largely overlooked despite the perceived value that it can bring to the study of institutional change. Nevertheless, most of the pertinent work applying InT to BIM adoption research has been led by Dongping Cao (Cao, Li, and Wang, 2014a; Cao et al., 2016; Cao et al., 2017). Cao and his research team draw on InT to explore the role of institutional isomorphic mechanism driving BIM adoption. These are shown in Figure 5.17 as coercive, normative, and mimetic pressures[3] (DiMaggio and Powell, 1983). The researchers found that coercive (i.e. regulatory) pressures and mimetic (i.e. competitive) pressures significantly influence the extent of project-level BIM adoption.

5.4 Theoretical Departure

Based on the discussions presented thus far in the study and the overview of existing theory established here, this section considers the gap in theory with regard to addressing the research problem. This section therefore discusses the rationale behind developing a unified conceptual framework to address the salient factors that affect BIM adoption, assimilation, and utilsation.

5.4.1 Limitations of Existing Theory

The publication landscape of BIM adoption displays a tendency to lean on behavioural change theories (i.e. Theory of Planned Behaviour and Theory of Reasoned Action) and technology acceptance models (e.g. the various iterations of the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology), Such theories and models are powerful explanatory tools for understanding innovation adoption behaviour under certain conditions. As exhibited by the MFTA (Figure 5.3), such theory could frame our understanding for BIM adoption at the micro-level.

However, these models are not without limitations. For example, the parsimonious nature of the TAM has led to criticisms that it does not consider any non-technological constructs, such as social factors, beyond the ambiguous External Variables construct (Qin et al., 2020). This is because the simplicity of the TAM allows it to be applied to various contexts whilst retaining acceptable levels of explanatory power. TAM and UTAUT

[3] These three isomorphic pressures can also be seen in the *Macro-Diffuion Dynamics Model* developed by Succar and Kassem (2015) See Section 2.2 for more discussion.

have also been criticised for the assumption that the innovation is being adopted within a voluntary environment by autonomous individuals.

With regards to the study of BIM adoption, the application of behavioural-based theory as a lens is also not without concern and has been contended in several studies (e.g. Ahmed and Kassem, 2018). As noted by Gallivan (2001), these traditional models are likely to yield inconsistent results if certain conditions aren't met, such as:

- Where micro-level adoption is mandated by the organisation,
- Where innovations are considered systemic and are interdependent on their adoption by others within the user's network,
- Where extensive, specialised training is required to overcome knowledge barriers, and,
- Where innovation champions are the single point of contact for an organisation and therefore vouch for the innovation's use among employees.

As extensively discussed in the literature review in Chapter TWO, BIM can meet most if not all of these qualities, particularly when being implemented within a meso-level setting. Furthermore, these models and extensions thereof rely also on a limited understanding of the innovation under study as an incremental innovation. If applied to BIM, this runs the risk of interpreting BIM as a single technological tool, particularly when considering the application of IS-based constructs such as Trialability and Perceived Ease of Use. This restrictive view of technology is also reflected in the language used by Rogers (2003), who uses the terms *innovation* and *technology* synonymously.

Other theory not derived from behavioural change such as the Technology-Organisation-Environment framework, Task-Technology-Fit, and Institutional Theory also bear limitations regarding the present study, primarily in their focus on meso-level implentation and change (Turk, 2016). For example, the nature of the InT's constructs rely on a rich understanding of how an organisation or project works, thereby being more suited to explaining local rather than widescale, or even microlevel, phenomena. This can be demonstrated through the propensity of studies to embrace a case study approach (e.g. Ho and Rajabifard, 2016). However, meso-level theory can still bring value to the study of BIM adoption at the micro-level. This is because the manner in which an organisation has implemented BIM can provide explanation as to how an individual behaves, through how policy changes are diffused through the organisation. For this reason, the mechanisms in place within an organisation is argued to exert some level of influence on an individual's actions.

These limitations of the theoretical models therefore suggest a more comprehensive conceptual framework would be appropriate for studying BIM adoption and utilisation at the micro-level. This is supported by Ahmed and Kassem (2018), who argue that the application of a specific, predetermined theoretical lens to BIM adoption delimits the consideration of other appropriate adoption constructs that would otherwise be dispersed amongst the many theoretical models and frameworks. Additionally, BIM adoption studies which have used these theories and models, either in their original forms, by adding constructs to them, or by combining them, have demonstrated support for several constructs and relationships. Therefore, these salient constructs can be integrated into the current research model, based on well-tested theory and empirical support.

5.4.2 The Need to Extend Beyond the "Dominant Paradigm"

The evolution of IS-based innovation theory and its derivatives has yielded significant insights into many facets of human behaviour within technology research. However, whilst not inherently flawed and indeed useful in the arenas for which they were intended, the sole and oftentimes default reliance on these theories restricts innovation adoption knowledge from progressing in an influential capacity. Fichman describes this effect as "reaching the point of diminishing returns" (2004, p.315), citing the apparent abatement of novel theoretical perspectives and the abundance of research as its causes. Extensive reviews by Fichman (2004) and, later, Jeyaraj et al. (2006) highlighted an emergent generalised theoretical structure, or so-called *dominant paradigm*, underpinning a vast accumulation of IS-based innovation research. Fichman's criticism of moving towards a formulaic approach to innovation study was reinforced by the ability of Jeyaraj et al. (2006) to derive generic relationships using aggregated constructs to explain innovation adoption by an individual or an organisation.

The dominant paradigm describes the tendency of research and theoretical models to rely on a simple linear relationship between the quantity of the “right stuff”, such as environmental and enabling characteristics, and the resulting quantity of innovation, such as the earliness or greater frequency of adoption. If mapped as a causal path diagram, the former act as independent variables that positively influence the latter as dependent variables (see Figure 5.18). The paradigm therefore posits that units of adoption who possess “more” of the right independent variables will enjoy “more” of the innovation, a view which is rooted in pro-innovation bias[4] (Fichman, 2004).

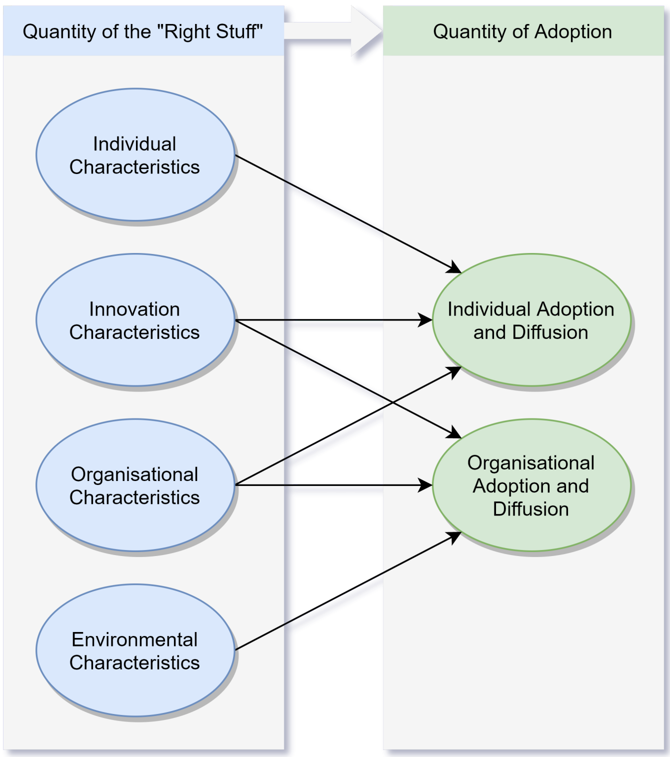


Figure 5.18 The dominant paradigm of IS innovation, adapted from Fichman (2004) and Jeyaraj et al. (2006).

The dominant paradigm tends to neglect the consequences of adoption. Instead, the predominant focus of the dominant paradigm of innovation adoption theory lies with initial adoption behaviour and acceptance, rather than continuance (Bhattacherjee and Barfar, 2011) or confirmation (Rogers, 2003). However, as noted by Bhattacherjee (2001), the

[4] Pro-innovation bias is defined as "the implication [...] that an innovation should be diffused and adopted by all members of a social system" (Rogers, 2003, p.100)

viability of the innovation and thus its success is dependent on its continued use. In a later study by Bhattacherjee and Barfar state "the expected benefits of a given IT cannot be realized and its implementation cannot be considered successful if its usage is not sustained over the long-term by the users who are expected to benefit from its usage" (2011, p.2). Yet, as briefly explored in the discussion of the ISSM, the study of innovation adoption consequences is generally limited (Delone and Mclean, 2003; Rogers, 2003; Petter, DeLone, and Mclean, 2008).

The argument against the dominant paradigm does not discount the value of applying the core theoretical models in modern innovation adoption research, but instead advocates a configurational approach to theory construction. Rather, the powerful set of tools that structure the core set of theoretical frameworks provide a strong foundation on which to generate more complex and sophisticated models which reflect the nuances and distinctive characteristics of the innovation they intend to describe. This includes the ability to introduce novel constructs and relationships which may explain phenomena yet to be understood for even well-versed IS-based innovations (Fichman, 2004). Most notably, Fichman (2004) posits that such an approach is particularly compatible with so-called "enterprise-scale IT innovation initiatives" which are large in scale and complex in nature. Such initiatives align with our understanding of systemic innovations, which is reiterated by Fichman's given examples of Enterprise Resource Planning (ERP) and other meso-level digitisation strategies.

5.4.3 The False Dichotomy of Adoption and Use

Whilst IS-based theory has the potential to provide rich insights into BIM adoption and utilisation, the derivation from innovations framed around IT has led to approaching the fact as a dichotomy, i.e. users either adopt, accept, or use it, or they do not (Jeyaraj, Rottman, and Lacity, 2006). This criticism has also been acknowledged by BIM adoption scholars. For example, Poirier, Forgues, and Staub-French (2017) criticise the application of leading theories, such as TAM and TPB, for their lack of explanation for behaviour extending beyond so-called adoption triggers for a dichotomous adoption decision. The authors substantiate the role of BIM as a systemic, modular innovation by scrutinising the tendency to treat BIM as a simple innovation, such as a software tool, in theoretical arenas. Furthermore, as highlighted in the discussion of the DOI, there is an increased reliance on constructs pertaining to the technical attributes of the innovation which may exacerbate the presentation of BIM as a localised innovation or single artefact.

Therefore, by approaching BIM with an IS theoretical lens borne from incremental innovations, we may be inhibiting our ability to derive real, valuable insights regarding BIM usage by simplifying our understanding of its adoption and use processes. This is not a novel observation; notwithstanding the composition of a modular innovation, IS researchers argue that a binary variable is insufficient in capturing the nuances of innovation adoption behaviour in general (e.g. Fichman, 1992; Swanson, 1994; Ravichandran, 2000; Frambach and Schillewaert, 2002; Ansari and Zajac, 2010; Sung and Choi, 2014). Yet adoption acts such as diffusion within an organisation are still treated as dichotomous (e.g. Kale and Arditi, 2010; Ganter and Hecker, 2014). Petter et al. (2008) also highlight the treatment of innovation use as a dichotomous variable, yet state "it is rarely ever either totally voluntary or totally mandatory" (2008, p.256). As Singh (2014) assert, this has led to an emergence of terms pertaining to the extent of adoption or use activity, whether by the individual (e.g. aggregation, assimilation, or routinisation) or across a group of individuals (e.g. diffusion, assimilation, or dissemination). This is particularly true of modular innovations: as a fundamental shift in process and a significant investment requirement, implementation within an organisation should be conducted over a period of time to ensure that capabilities are built and processes are aligned.

However, as argued in Chapter TWO and corroborated in Chapter FOUR, there is an apparent gap between an individual's perceived adoption and their actual use, and therefore a need to measure microlevel assimilation. The consideration of assimilation as a construct has generally been neglected in innovation adoption literature, particularly when approaching from a micro-perspective (Liu et al., 2011; Enkel et al., 2017). Most scholarly attention has been restricted to considering assimilation from an organisational perspective (e.g. Fichman and Kemerer, 1997; Cho and Kim, 2002; Hossain et al., 2011).

Yet, organisational absorptive capacity, as defined in Section 2.2.3, is highly dependent on the concept of individual absorptive capacity (Cohen and Levinthal, 1990; Park, Suh, and Yang, 2007). However, scholars such as Cohen and Levinthal (1990) and, more latterly, Liu et al. (2011) argue that assimilation should be approached from a multi-level perspective as assimilation occurs at the micro- and meso-levels simultaneously. Therefore, the construct of individual assimilation should be explored as a novel factor within the present study.

5.5 CONCLUDING REMARKS

This chapter has presented the second and last section of the literature review, which set out to examine the application of relevant theoretical models and frameworks. It has provided an overview of how the existing but limited body of work concerning BIM adoption is drawing from the IS domain to generate theoretical understanding. This chapter has also briefly touched upon the implications of using the level of analysis as a lens through which to assess these models and frameworks. This review complements the narrative developed in Chapter TWO, in which BIM was appraised as a systemic innovation, or an interacting set of sociotechnical elements, rather than a singular technological article. As such, this chapter has used this lens to discuss the limitations of applying an existing IS-based framework to BIM adoption and has outlined the rationale for developing a unified conceptual framework to address these shortcomings.

In undertaking a review of the most common theoretical models and frameworks with IS innovation adoption literature, Chapter FIVE has addressed Research Objective 2. By assuming a pragmatic approach to developing the conceptual framework for the present study, novel constructs that have been neglected in innovation adoption literature can be proposed and addressed whilst building on the foundations established in prior study regarding existing constructs. Chapter SIX will therefore draw upon the findings presented in this chapter and discuss the development of an integrated conceptual model for exploring the key factors influencing micro-level BIM adoption, assimilation, and utilisation.

CHAPTER SIX

THE CONCEPTUAL FRAMEWORK

Chapter SIX uses the narrative built by the previous chapter to introduce and discuss the conceptual research model, its constructs, and the development of the associated hypotheses. As posited in Chapter FIVE, the core theoretical models derived from Information Systems (IS) and innovation adoption literature are insufficient in dealing with BIM adoption when taken in isolation. The subsequent discussion presented the case for the development of a unified conceptual model for understanding BIM adoption, assimilation, and utilisation. Moreover, the findings of Phase I, coupled with the critique of the theoretical models and frameworks presented in Chapter FIVE, will help formulate an appropriate conceptual model which aims to respond to the practical challenges identified within the exploratory study. This chapter introduces the salient constructs of the proposed model and concludes with the presentation of the research hypotheses.

This chapter addresses Research Objective 3, which was to develop an integrative framework for BIM adoption by considering key constructs from the assessed models and theories, and any further novel constructs identified in BIM literature and the exploratory research.

6.1 DEVELOPMENT OF THE CONCEPTUAL FRAMEWORK

Following the analysis of emergent issues from the literature review chapters and exploratory study, this section presents the conceptual framework for analysing BIM adoption, assimilation and utilisation by individuals within the UK's AECO sector. To understand the issues associated with BIM adoption, assimilation, and utilisation, it is necessary to have an empirically validated theoretical framework that addresses the research problem whilst overcoming the limitations of existing theory as discussed in Section 5.4.1. Therefore, from the literature review and the exploratory study presented in Phase I, the conceptual model shall meet the following requirements:

1. It should support a configurable approach to theory construction by drawing on empirically validated constructs and relationships within established theory,
2. It should attempt to move away from interpreting the act of adoption and utilisation as a dichotomy, and
3. It should attempt to capture the broader nuances of BIM as a systemic, modular innovation by extending beyond its technical capabilities.

This section will therefore discuss the process of developing the underlying framework for the conceptual model. As introduced in Chapter TWO, to further establish the cohesive ontology surrounding BIM adoption research, the key terms and concepts within this section will align with the terminology employed by the Unified BIM Adoption Taxonomy (UBAT) developed by Ahmed and Kassem (2018). The terminology therefore employs drivers and factors to describe categories of constructs.

6.1.1 At the Macro-Level

The narrative presented in Chapter TWO highlighted the practical, real-world implications of BIM adoption by addressing the need for appropriate macro-level metrics and by highlighting the dearth in cohesive upskilling provision and policy. Therefore, to drive the discussions around developing the conceptual model to underpin the present study, the underlying framework draws on the UK BIM mandate to structure its focal relationships at the macro-level.

The BIS BIM Strategy report introduced a working, non-descriptive hypothesis for guiding and validating the UK's BIM journey. The hypothesis stated that "Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information" (BIM Industry Working Group, 2011, p.15). The hypothesis suggests a positive causal relationship between what was later defined as the Level 2 BIM mandate (Cabinet Office, 2011) and efficiency gains achieved through measurable improvements in cost, value, and carbon performance.

The role of government as the change agent to stimulate top-down BIM diffusion (Section 2.2.1) to realise quantifiable, industry-wide benefits (Section 1.1.2) allows us to extrapolate this hypothesis to a macroperspective. Therefore, transposing the hypothesis into a causal path diagram as shown in Figure 6.1 using terminology aligned to the Multilevel Framework for Technology Adoption (MFTA), the BIM Discourse is theorised to influence its Diffusion, which is in turn shown to have a positive relationship with Net Benefits. In other words, the government's promotion of BIM is said to influence the extent of industry adoption, and the more BIM diffuses across industry, the more industry will reap the associated benefits.

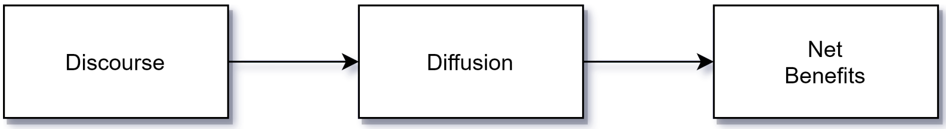


Figure 6.1 A macroperspective of the conceptual framework

Given the scale and inherent complexity of the AECO industry, the ability to use this model as a tool to explore industry diffusion and its relationships is greatly impacted. This reiterates the narrative of Taylor and Levitt (2004a) who recognised that innovation diffusion modelling is a rarely exercised technique within the construction research domain. However, applying the methodological individualism principles enshrined within this thesis as promoted by the MFTA (Tscherning, 2011), the macroscopic view presented in Figure 6.1 can be used to frame the micro-level model for this research. Moreover, the microscopic perspective will enable constructs to be drawn from the theoretical models and frameworks presented in the previous chapter. Therefore, Figure 6.1 presents a frame against which to structure the focal relationship of the conceptual model for this research.

6.1.2 At the Micro-Level

Akin to the relationship between Use and Net Benefits within the ISSM, this study posits that an individual's Perceived Extent of Use has a direct relationship with Perceived Use Outcomes. Building on the discussions in the previous chapter, it is recognised that utilisation-related constructs tend to be informed by a multitude of characteristics, or antecedent constructs. An antecedent construct is defined within the social sciences as a variable which "precedes the focal independent variable to explain its genesis" (Aneshensel, 2015, p.288). Therefore, in line with the macroperspective, Perceived Extent of Use is shown to be influenced by an external characteristic which has been captured within the model as Antecedent Drivers. Additionally, a further construct pertaining to the Actual Extent of Assimilation is shown to mediate the relationship between Perceived Extent of Use and Perceived Use Outcomes, whilst also being influenced by Antecedent Factors. These relationships attempt to capture the gap between the rhetoric and reality of use behaviour, as characterised by the assimilation gap effect described in Section 2.2.3. These relationships are illustrated in Figure 6.2.

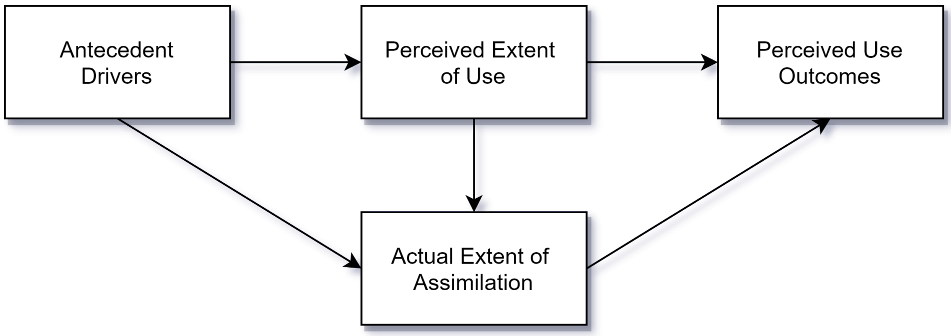


Figure 6.2 A microperspective of the conceptual framework

This microperspective provides an overarching framework for developing the conceptual model for this study. The following sections will therefore discuss how each construct was conceptualised based on empirical support from existing studies and from within established theory. The constructs are presented as drivers and factors, in accordance with the UBAT.

6.2 CONCEPTUALISATION OF THE ANTECEDENT DRIVERS

This section introduces and discusses the antecedent drivers. Two antecedent drivers affecting adoption behaviour are identified: Foundational Traits (FT), which are the internal characteristics of the actor, and Environmental Influences (EI), which are the characteristics external to the actor. Figure 6.3 illustrates these relationships.

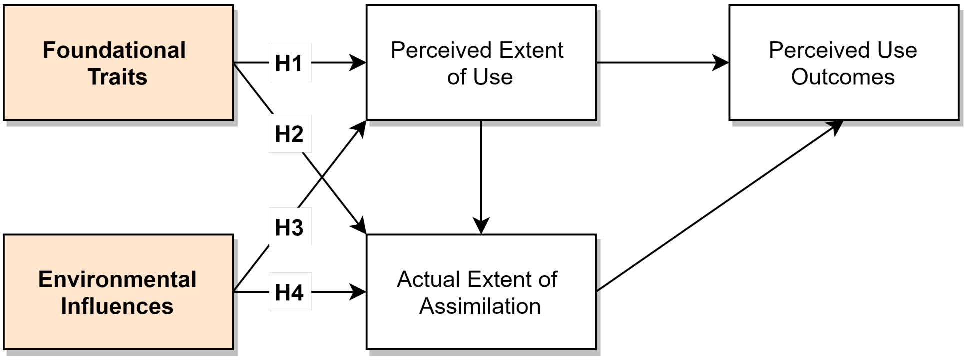


Figure 6.3 Antecedent drivers: Foundational Traits and Environmental Influences

Based on this figure, the following hypotheses have been developed:

Hypothesis 1. *Foundational Traits (FT) have a direct relationship with Perceived Extent of Use (PEU).*

Hypothesis 2. *Foundational Traits (FT) have a direct relationship with Actual Extent of Assimilation (EA).*

Hypothesis 3. *Environmental Influences (EI) have a direct relationship with Perceived Extent of Use (PEU).*

Hypothesis 4. *Environmental Influences (EI) have a direct relationship with Actual Extent of Assimilation (EA).*

The factors for each of these drivers and the sub-hypotheses will be discussed in the following sections.

6.2.1 FOUNDATIONAL TRAITS

Personal attributes or variables are generally neglected in innovation adoption research (Rogers, 2003). Most of the adoption models discussed in Chapter FIVE generally do not consider personal attributes to be salient constructs and instead relegate their role to moderators, as seen with the gender, age, and experience factors in the UTAUT and TAM2. Yet, the dominant paradigm dictates that individual characteristics are a predictor for the adoption and use behaviour of individuals (Jeyaraj, Rottman, and Lacity, 2006). In addition, an individual's personal traits have been shown to play a significant role in defining their level of competency. As stated within the Project Management Institute's Body of Knowledge, an individual's personal competency is "the behaviours, motives, traits, attitudes, and self-concepts that enable a person to successfully manage a project" (PMI, 2013).

Within the context of BIM, Succar et al. (2013) outline the individual's personal attributes as one of three core components of their BIM competency alongside knowledge and skill. The authors describe these as *Foundational Traits* which are the "personal attributes inherent in an individual that cannot be acquired through training or education" (Succar, Sher, and Williams, 2013, p.180). The present study conceptualises Foundational Traits to be a driver to three factors: Attitude Toward BIM, Self-Efficacy, and Risk Propensity. The rationale behind each factor is discussed in this section.

Attitude Toward BIM (FT-AT)

An individual's attitude towards an innovation is purported to play a formative role in influencing behavioural intent to use an innovation (Fishbein and Ajzen, 1975). Rogers (2003) uses the innovation-decision process to illustrate this; to first consider the adoption of an innovation, the individual be aware of and gain knowledge on the innovation before shaping their attitude in what Rogers terms the 'persuasion stage' of the process – refer to Figure 5.6. The persuasion stage is where the individual forms either a favourable or unfavourable attitude towards using the innovation, which in turn influences their decision to either adopt or reject it. In addition to this individualistic view, shared attitudes between individuals within a population can create homophily and promote – or conversely, demote – innovation diffusion by engaging in more effective communication channels within the network (Rogers, 2003).

The Attitude Toward BIM construct is adapted from Attitude Toward Using variable within the the TRA, TPB, and TAM models. Although this construct was omitted in later models within the IS theory suite explored in the previous chapter, evidence suggests that the individual's attitude plays a critical role in influencing the decision to use BIM. For example, BIM adoption studies frame Attitude as synonymous with User Satisfaction (e.g. Song et al., 2017; Dowsett and Harty, 2018). However, this is a somewhat reductionist view of the Attitude construct by structuring the user's emotive response to BIM as a simple linear spectrum (i.e. from satisfied to unsatisfied), rather than being it being curated by a series of beliefs informed by knowledge-procurement exercises (Fishbein and Ajzen, 1975; Rogers, 2003).

However, this is not to say user satisfaction cannot itself be influenced by the Attitude variable. For example, Wang and Song (2017) found that a BIM user's attitude strongly impacts on the user's perceived usefulness and ease of use of BIM technology, which in turn influences user satisfaction. A study by Xu et al. (2014) also found Attitude to influence perceived ease of use, but instead framed Attitude as a driver comprised of perceived cost, interest in learning, and willingness to use factors. The Attitude driver was found to be the biggest barrier to BIM adoption, more so than organisational drivers, such as the availability of BIM training, and technological drivers, such as system interoperability and compatibility.

Howard et al.(2017) also considered Attitude by reintroducing it as a variable within the UTAUT model in their study of BIM adoption. The authors acknowledged a strong body of literature which highlights the UTAUT's neglect to consider the influence of an individual's attitude towards an innovation within a setting where its use is mandated. Interviews conducted with industry practitioners further supported the inclusion of Attitude within the research model. Moreover, the study found Attitude to significantly influence Use Behaviour, more so than Behavioural Intent as theorised within the TRA, TPB, and

TAM. This effect was attributed to the use of BIM within a mandatory setting. Therefore, following the recommendations of Howard et al. (2017), Attitude Toward BIM is included in the present study as a distinct construct and the following hypothesis is developed:

Hypothesis 1a. *There is a positive relationship between an individual's attitude toward BIM and their perceived extent of BIM use.*

Within the context of developing an undertanding of BIM competency, Attitude has been shown to be a core element alongside knowledge and skill (e.g. Hoffmann, 1999; PMI, 2013; Succar, Sher, and Williams, 2013; Bush and Robinson, 2018) and is considered as one of the critical core competencies required for project management (Stevenson and Starkweather, 2010). This is because Attitude "can enhance individual members' [...] interest in learning BIM technology and thereby improve the chances of successful adoption" (Xu, Feng, and Li, 2014, p.42). Therefore, this study proposes the following hypothesis:

Hypothesis 2a. *An individual's attitude toward BIM is positively associated with the actual extent of assimilation.*

Self-Efficacy (FT-SE)

Although not directly referenced as a construct within the suite of theoretical models and frameworks reviewed in Chapter FIVE, Self-Efficacy has been documented as a core construct relating to how an individual understands their ability to act upon a certain behaviour. Rather, Self-Efficacy, as conceptualised by Bandura (1986), forms much of the grounding for TAM's assertion that the Perceived Ease of Use and Perceived Usefulness of a technological innovation serves as determinants for user behaviour (Davis, 1989). In other words, it is theorised that those who possess low Self-Efficacy do not have the confidence to exert behavioural control in relation to the use behaviour (Ajzen, 1991), such as the adoption of an innovation (Rogers, 2003).

Compeau and Higgins (1995) developed the concept of Self-Efficacy further to apply it directly to an innovation adoption context, by conceptualising the so-called Computer Self-Efficacy factor. This refined the focus of the original construct to consider the individual's contextualised beliefs about their computer abilities specifically, which is theorised to influence how they engage with tasks. This can be demonstrated by the work of Son et al. (2015) who found Computer Self-Efficacy to be a predictor of Perceived Ease of Use when applied in a BIM context. However, this perception of Self-Efficacy perpetuates the tool-focused approach to BIM acceptance in a manner similar to the Effort Expectancy and Complexity variables promoted by the UTAUT and DOI respectively. Therefore, Computer Self-Efficacy is not appropriate when considering BIM beyond its technology.

However, a broader Self-Efficacy measure may be more applicable. For example, Riggs et al. (1994) developed measures pertaining to Efficacy at the micro- and meso-levels, which were considered agnostic to any specific task. Whilst they acknowledge the likelihood to achieve more accuracy when considering item construction around a specific application, the authors highlight the value of a standardised construct to compare Personal Efficacy across job roles. This broader conceptualisation of the Self-Efficacy construct has been used within BIM adoption research. For example, in their study of BIM-related resistance behaviours, Wang et al. (2020) considered Self-Efficacy within the context of broader IT and found it to positively impact on the Perceived Usefulness and Perceived Ease of Use of BIM constructs. The authors group Self-Efficacy with Personal Innovativeness to describe the micro-level contextual factors affecting perceptions around behavioural resistance to BIM implementation. Similarly, Lee et al. (2015) propose that an individual's personal competency is comprised of Self-Efficacy and Personal Innovativeness, which is echoed again by Lee et al. (2017) in their discriminant analysis. Notably, the latter found those who accept BIM to have higher levels of perceived Personal Efficacy than those who do not. Therefore, the hypothesis is as follows:

Hypothesis 1b. *There is a positive relationship between an individual's perceived self-efficacy in relation to their job, and perceived extent of use of BIM.*

Wang et al. (2020) suggest that individuals who possess a higher perceived sense of Self-Efficacy with regard to IS innovation use will be more likely to assimilate more complex technologies, such as BIM. On the other hand, Akintola et al. (2017) argue that individuals who perceive themselves to lack BIM-specific Self-Efficacy will bridge this perceived gap in capability by outsourcing BIM functions, which has been found to be less efficient that in-house implementation (Fountain and Langar, 2018). Therefore, perpetuated beliefs regarding ones' BIM-related Self-Efficacy and the continued reliance on outsourcing culture could further contribute to the perceived assimilation gap in industry by not sufficiently addressing upskilling needs. It therefore stands to reason that an individual's perception of their own capabilities in relation to the adoption and use of an innovation is inherent to the individual's ability to effectively assimilate and use an innovation. Based on this assertion, the following hypothesis is proposed:

Hypothesis 2b. *An individual's perceived self-efficacy in relation to their job is positively associated with their actual extent of assimilation.*

Risk Propensity (FT-RP)

Notwithstanding the inherently risk-adverse nature of the AECO industry itself, BIM has been shown to have technical, management, environmental, financial, and legal risks associated with its adoption (e.g. Azhar, 2011; Chien, Wu, and Huang, 2014; Wang, Liu, and Wang, 2016; Ghaffarianhoseini et al., 2017; Jin et al., 2017; Ozorhon and Karahan, 2017; Zhao, Wu, and Wang, 2018). However, the construct of micro-level risk behaviour has not been well studied in not only BIM adoption research, but also in the wider IS domain. Nevertheless, there appears to be a growing recognition for its cousin, Personal Innovativeness (Agarwal and Prasad, 1998).

Rogers sought to categorise adopters based on an individual's innovativeness, or "the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a social system" (Rogers, 2003, p.261). This concept correlates with the degree of risk tolerance of adopter categories; innovators and early adopters are more willing to embrace risk and adopt an innovation with little evidence backing it, whereas the late majority and laggards prefer to see empirical evidence before they take any risk (Rogers, 2003). This definition is further developed by Agarwal and Pasad, who define Personal Innovativeness as the "risk seeking behaviour" and "willingness of an individual to try out an innovation" (Agarwal and Prasad, 1998, p.18) by recognising the inherent risks associated with embracing a new innovation.

As mentioned in the discussions surrounding Self-Efficacy, Personal Innovativeness has been used in BIM adoption research as part of the dyad comprising an individual's Personal Competency (Lee, Yu, and Jeong, 2015; Lee and Yu, 2016). Personal Innovativeness has also been found to be one of the discriminating factors between those who accepted BIM and those who did not (Lee and Yu, 2017). However, within a work-based context in which adoption tends to be driven by external bodies or internal mandates, the individual's Personal Innovativeness or other actual risk taking behaviours may be inhibited due to environmental limitations.

Rather, assuming the view of Sitkin and Pablo (1992), risk behaviour and personal innovativeness are prefaced by the individual's Risk Propensity, or their tendencies to generally take risks. As the authors state, "a focus on tendencies recognises that the general desire to pursue or avoid risks (i.e. risk preferences) does not determine specific risk behaviours, but rather it affects the general likelihood of a person's behaving in more or less risky ways" (Sitkin and Pablo, 1992, p.15). Therefore, in line with the findings of Lee et al. (2017), it is suggested that individuals with higher degrees of Risk Propensity are more likely to experience greater perceived use of BIM than those who prefer to take less risk. This is set out in the following hypothesis:

Hypothesis 1c. *The individual's risk propensity in construction projects is positively associated with their perceived extent of use.*

Similarly, it can be argued that individuals with higher levels of Risk Propensity are more likely to invest in and embrace assimilation processes. Therefore, the second hypothesis relating to Risk Propensity is as follows:

Hypothesis 2c. *The individual's risk propensity in construction projects is positively associated with their actual extent of assimilation.*

6.2.2 Environmental Influences

In established IS theory, factors which influence the environment in which the actor under study operates are typically shown to play an antecedent role to the actor's adoption and use of an innovation. For example, the models derived from behavioural change theory, such as TRA, TPB, and UTAUT, frame these environmental characteristics as distinct independent variables, such as Facilitating Conditions, Social Influence, and Subjective Norm. TAM also highlights this antecedent role but instead of theorising relationships between specific factors, it rather uses the generic External Variables construct to highlight the ability of the model to adapt to innovation adoption in varying environments.

When adapting TAM for studying BIM acceptance, Lee et al. (2015) note that the External Variables construct plays in influencing an innovation's Perceived Usefulness and Perceived Ease of Use. However, the authors also note that there has been little consensus or emerging pattern surrounding how these variables are selected. The authors instead contextualise the construct for use within their own study, which defines External Variables, as structured in TAM, as "key factors affecting the acceptance of BIM in construction organisations" (2015, p.4). However, this definition draws on meso-level rather than micro-level acceptance. Moreover, this definition aligns with the interpretation of environmental characteristics as overarching drivers, in which various contextual factors are grouped and treated as having a shared relationship with the dependent variable under study. This is akin to the theoretical underpinnings presented within the TOE Framework; this model presents relationships between the internal environment (i.e. the various characteristics of the adopting organisation) and the external environment (i.e. the influencing characteristics of the wider industry) without drawing on relationships between distinct variables within these drivers.

However, as the focus of the research resides with the actor at the micro-level, it is argued that these internal and external environments exert a collective environmental influence on the individual. The influence of the organisational environment and the wider external environment on micro-level adoption has been studied to varying degrees: external environmental characteristics tend to be studied as predictors for meso-level adoption, whereas organisational characteristics are shown to be important predictors for both micro- and meso-level adoption (Jeyaraj, Rottman, and Lacity, 2006). Rather, by approaching these environmental characteristics as a single driver, this research responds to the recommendations of IS scholars by continuing to examine established predictors of micro-level adoption of different innovations, and also by drawing on predictors which have generally been neglected at this level of study (Jeyaraj, Rottman, and Lacity, 2006).

The driver, Environmental Influence, is captured within this study through four factors: External Pressures, Facilitating Conditions, Top Management Support and Subjective Norms.

External Pressures (EI-EP)

The first Environmental Influence factor relates to the External Pressures to adopt the innovation. Traditional IS theory deals with External Pressures in various ways. Within DOI, the roles of the nature of the social system, the type of communication channels, and the extent of the change agents' promotion effects are framed as predictors for the rate of adoption, all of which have connotations pertaining to the exertion of pressure. Within the TOE framework, the External Task Environmental context is used to investigate, among others, the pressures enacted on the decision-making process by entities external to the decision-making actor, such as government regulation. Although not pertaining exactly to External Pressures, the TAM uses the ambiguous External Variables construct to allow research to input external constructs relevant to the study, which can include environmental influences (e.g. Qin et al., 2020). However, the most explicit role of External Pressures is presented in Institutional Theory (InT). As discussed in Section 5.3.8, InT posits that there are three types of isomorphic mechanisms governing institutional change: coercive pressures (i.e. pressure from regulatory agencies, change agents, or trade partners), mimetic pressures (i.e. pressure from competitors), and normative pressures (i.e. pressure from professionalisation and collective behaviours) (DiMaggio and Powell, 1983). These isomorphisms have since been applied to describe BIM diffusion mechanisms (refer to Section 2.2.1) and as a driver within the UBAT (Ahmed and Kassem, 2018)

Within BIM adoption research, Cao et al. (2014b) investigated the influence of the three isomorphic pressures on the extent of BIM adoption at the project-level and on client/owner behaviour. When assessed based on a direct relationship between the pressure factors and BIM adoption, the authors found coercive and mimetic pressures to have a significant effect on BIM adoption. Moreover, the study found client/owner support to be a significant mediating factor in the relationship between these pressures and BIM adoption, although both models indicated little support for the role of normative pressures in line with the findings of Bosch-Sijtsema et al. (2017).

Within their BIM Acceptance Model, Lee et al. (2015) conceptualised Behaviour Control as the overarching driver to Internal and External Pressures. Internal Pressures related to the pressures coming from within the organisation, such as from superiors and colleagues, whereas External Pressures pertained to pressures from within the external environment, such as competitors. The authors found Behaviour Control (i.e. both Internal and External Pressures) to have a significant relationship with both the individual and organisational intention of acceptance. However, this has been shown not to be ubiquitous: for example, studies in India, which is only just embracing BIM on a macro-level, have demonstrated a lack of support or pressure from governments and clients (Ahuja et al., 2016; Ahuja et al., 2020). Yet, in China, national policy and competitive conditions are key drivers for BIM implementation (Qin et al., 2020), as is the case in the UK (e.g. Eadie et al., 2013a; Kassem and Succar, 2017).

As the UK's BIM discourse is built on isomorphic diffusion principles, External Pressures are conceptualised within this study those concerning pressures from the government, clients, and competitors. Moreover, this study considers there to be a relationship between the External Pressures construct and the Perceived Extent of Use. This is hypothesised below:

Hypothesis 3a. *There is a positive relationship between external pressures and an individual's perceived extent of use of BIM.*

Hypothesis 4a. *There is a positive relationship between external pressures and an individual's actual extent of assimilation.*

Facilitating Conditions (EI-FC)

Within technology adoption theory, the Facilitating Conditions construct was introduced within the UTAUT to describe the perceived level of organisational support and technical infrastructure facilitating the individual's adoption and use of an innovation (Venkatesh et al., 2003). Addy et al. (2018) argue that it has conceptual synergies with compatibility (Moore and Benbasat, 1991; Rogers, 2003; Venkatesh et al., 2003; Davies and Harty, 2013a) and perceived behavioural control (Ajzen, 1991; Taylor and Todd, 1995; Venkatesh et al., 2003; Bhattacherjee et al., 2015). Synergies also exist with the factors within the External Task Environment and Organisation contexts within the TOE framework - see Figure 5.13.

Within the setting of the UTAUT, Facilitating Conditions is posited to directly influence use behaviour, although moderated by the user's experience and age (Venkatesh et al., 2003). Support has also been demonstrated for including the construct as a predictor for continuance behaviour in an extended IT continuance model (Bhattacherjee et al., 2015). However, Jeyaraj et al. (2006) suggest that the use of Facilitating Conditions as a construct in innovation adoption research should be carefully considered. This is because the authors found little empirical support for the construct's role in predicting IT adoption by individuals following an extensive systematic review.

This present study argues that the adoption of systemic, business-aligned innovations inherently requires external support to facilitate adoption at the micro-level. Moreover, support for the construct can be demonstrated in BIM adoption literature. For example, Howard et al. (2017) found Facilitating Conditions to have the greatest impact on individuals' actual user behaviour out of all factors investigated. Addy et al. (2018) also highlighted a positive relationship between Facilitating Conditions and behavioural intention. In both studies, the Facilitating Conditions construct was found to correlate with effort expectancy, suggesting that "the more user-friendly BIM becomes, the better the perception of the Facilitating Conditions" (Howard, Restrepo, and Chang, 2017, p.116). Although this may misconstrue the concept of BIM and present it as a single application, there are implications surrounding the perceived effort surrounding adoption and assimilation activities. Addy et al. (2018) argue that this is particularly relevant for developing countries where secure internet access and reliable electricity sources are a concern. This research assumes the view that Facilitating Conditions has a direct and positive influence on use behaviour and therefore proposes the following hypothesis:

Hypothesis 3b. *Facilitating Conditions (FC) is positively associated with an individual's Perceived Extent of Use (PEU) of BIM.*

The act of assimilating an innovation also requires an appropriate support structure, particularly when considering those of a systemic nature. This is supported by Hilal et al. (2019), who presented a case for considering Facilitating Conditions in the assessment of BIM adoption by FM professionals. Although not yet empirically tested, the authors conceptualise the construct as having a direct impact on BIM adoption by FM professionals, stating they require "to have specific skills such as dealing with BIM tools and feeding BIM with the consistent information and data" and that if they "users do not have these necessary operational skills and the financial resources, they will not adopt BIM" (Hilal, Maqsood, and Abdekhodaee, 2019, p.543). Therefore, this study proposes the following hypothesis.

Hypothesis 4b. *Facilitating Conditions (FC) has a positive effect on an individual's Actual Extent of Assimilation (EA) of BIM.*

Subjective Norms (EI-SN)

The Subjective Norms construct regards the social influences surrounding adoption and use behaviour. However, unlike the External Pressures construct, Subject Norms pertains to the internal influences within the organisation, and is particularly important when considering implementation within a mandatory setting (Venkatesh and Davis, 2000). The construct was introduced in the TRA, in which it acts as the independent factor to Behavioural Intention (Fishbein and Ajzen, 1975; Ajzen, 1991). The TAM2 also supports this relationship, in addition to proposing direct relationships with Perceived Usefulness and Image (Venkatesh and Davis, 2000). When developing the UTAUT, Venkatesh et al. (2003) later subsumed Subjective Norms into a broader construct pertaining to Social Influence, including Image[1] and Social Factors[2]. Within general IS-based innovation

[1] Defined as the degree to which use of an innovation is perceived to enhance one's image or status in one's social system (Moore and Benbasat, 1991)

[2] Defined as the individual's internationalisation of the reference group's subjective culture, and specific interpersonal agreements that the individual has made with others in specific social situations (Thompson, Higgins, and Howell, 1991)

adoption research, Subjective Norms have also been identified as one of the best predictors of behavioural intention to use an innovation (Jeyaraj, Rottman, and Lacity, 2006).

Within the BIM adoption context, Subjective Norms and its relation Social Influence are critical when considering the coordination activities inherent to the BIM workflow. This can be likened to the ERP context, in which social factors are the most significant determinant for ERP system usage (Chang et al., 2008). Rather, it has been found that the social aspects can be larger barriers to effective implementation than the technical barriers (e.g. Chang et al., 2008; Eadie et al., 2015; Oesterreich and Teuteberg, 2019). Moreover, empirical research is demonstrating support for the role of these social constructs in BIM adoption activities. For example, Howard et al. (2017) found Social Influence, as defined by the UTAUT, to have the largest influence on Behavioural Intention. This aligns the findings of Gholizadeh (2018) who found "bandwagon pressure" to be the primary source for diffusing BIM functions amongst organisations. Drawing on traditional TRA relationships, Son et al. (2015) and Wang et al. (2020) both found Subjective Norms and Colleague Opinion to influence Perceived Usefulness respectively.

Within the context of isomorphisms, Cao et al. (2014a) found no support for their hypothesis concerning the relationship between normative pressures and the extent of BIM adoption. However, this does not align with the findings of Liang et al. (2007) who found normative pressures to directly influence usage in an ERP context. Cao et al. (2014a) note that their finding may be a result of conducting a study within a community with low levels of BIM diffusion, indicating results may differ if applied in a more established setting. However, the authors also demonstrate strong support for coercive and mimetic pressures, signifying that the role of social influence may be multidimensional, in line with the position assumed by Davies and Harty (2013a).

This discussion demonstrates a mixed approach to the conceptual understanding of internal influences on BIM adoption and use behaviour. Therefore, this study conceptualises Subjective Norms to be the influences exerted by co-workers and superiors as an attempt to ground the construct within an innovation-at-work context. To this end, the following hypothesis is developed:

Hypothesis 3c. *The subjective norms are positively related to an individual's perceived extent of use.*

This study also suggests that Subjective Norms can also influence assimilation behaviour, particularly with the early stages of implementation. As noted by Gallivan, "subjective norms shape potential adopters' beliefs about when and why to adopt an innovation [and] how much effort to undertake on their own to learn it" (2001, p.61). This suggests that if the individual is surrounded by people who's views they respect and put into practice, they will attempt to meet any expectations they may have through assimilation activities. Therefore, the following hypothesis is developed:

Hypothesis 4c. *The subjective norms are positively related to an individual's actual extent of assimilation.*

Top Management Support (EI-TM)

Although Top Management Support does not feature as a distinct construct within the traditional theoretical models discussed in the previous chapter, it often forms a key factor in the structuring and conceptualisation of organisation-related drivers, such as Organisational Context in the TOE Framework. Top Management Support's role is prevalent in IS-based innovation literature, with many studies confirming its influence on the adoption of other systemic innovations, such as Enterprise Resource Planning (ERP) (e.g Bajwa, Garcia, and Mooney, 2004; Liang et al., 2007; Law and Ngai, 2007). Jeyaraj et al. (2006) also identified it as one of the best predictors for both individual- and organisational-level adoption of IT, with the authors finding that, out of the 135 examined, it was the only reliable predictor for both individual and organisational adoption.

The support for the Top Management Support in BIM adoption literature is well documented, particularly at the organisational-level (e.g. Linderoth, 2010; Arayici et al., 2011a; Xu, Feng, and Li, 2014; Ahuja et al., 2016; Ahuja et al., 2020). For example, Attarzadeh et al. (2015) found that Top Management Support was one of two factors which were considered to be of high importance for BIM adoption across all phases of a construction project into operation and maintenance. Xu et al. (2014) found the senior management support to be the top ranked factor influencing BIM usage, due to in part their role in convincing stakeholders to support the initiative. In their study, Qin et al. (2020) demonstrated that greater Top Management Support may be achieved through increased standardisation of BIM within industry. In an early case study, Arayici et al. (2011b) found Top Management Support to be a critical success factor for BIM implementation within an architectural SME setting. Lastly, it has been suggested by Bosch-Sijtsema et al. (2019) that insufficient Top Management Support is perceived to be a greater barrier to effective implementation for BIM actors, even when compared to non-BIM actors. Therefore, the following hypothesis is proposed:

Hypothesis 3d. *There is a direct relationship between top management support and an individual's perceived extent of use.*

Top Management Support is critical in understanding how an organisation can adapt its business processes when such systemic innovations are being assimilated. This is because it can act as a proxy for organisational or executive-level attitude, which in turn, affects the extent of investment into an IS-based innovation's adoption process. As highlighted by Song et al. (2017) and Won et al. (Won et al., 2013), the cost of investment for BIM implementation, which includes both capital and continuous investments, can be substantial and are unlikely to be met in whole by the end users without input from top management.

Approaching the issue from a change management perspective, top management facilitates effective assimilation within an organisation through its support, mentoring, training, or mandating use (Gallivan, 2001; Peansupap and Walker, 2005). For example, Bosch-Sijtsema et al. (2019) found insufficient management support was a significant barrier for the professional development of BIM-related roles. A case study conducted by Arayici et al. (2011a) demonstrated that the adoption of BIM, even in circumstances where staff have little prior BIM-related knowledge or skill, can be successfully enacted if top management members are perceived to be proactive and engaged with the BIM rhetoric. This is because top management can support and enable an effective implementation programme, which, as shown in the case study, includes continuous staff upskilling and the development of technological infrastructure. Therefore, it is proposed that:

Hypothesis 4d. *There is a direct relationship between top management support and an individual's actual extent of assimilation.*

6.2.3 Operational Definitions

A summary of the conceptual and operational definitions for each of the constructs are presented in Table 6.1. The conceptual definition aims to succinctly capture the essence of the factors. To do so, definitions are drawn from seminal studies within IS and innovation adoption research. The operational definition aims to contextualise the construct to the assimilation and use of BIM, which will provide a framework for its measurement.

Table 6.1 Conceptual and operational definitions of the antecedent factors

Factor	Conceptual Definition	Operational Definition
Attitude Toward BIM (FT-AT)	"An individual's positive or negative feelings (evaluative affect) about performing the target behaviour" (Fishbein and Ajzen, 1975, p.216).	An individual's positive or negative feelings about assimilating and using BIM.
Self-Efficacy (FT-SE)	"The belief that one has the capability to perform a particular behavior" (Compeau and Higgins, 1995, p.189)	The belief that one has the capability to perform their job role.
Risk Propensity (FT-RP)	"The tendency of a decision maker either to take or avoid risks" (Sitkin and Pablo, 1992, p.12).	*As conceptual definition.*
External Pressures (EI-EP)	The influences arising from governments, clients, and competitors within the external environment (adapted from Eadie et al., 2013a; Lee, Yu, and Jeong, 2015)	*As conceptual definition.*
Facilitating Conditions (EI-FC)	"The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system" (Venkatesh et al., 2003, p.453)	The degree to which an individual believes that an organizational and technical infrastructure exists to support assimilation and use of BIM.
Subjective Norms (EI-SN)	"The individual perception that others believe that the individual think people should or should not perform certain acts" (Fishbein and Ajzen, 1975, p.329)	The individual perception that others believe that the individual think people should or should not adopt, assimilate, and use BIM.
Top Management Support (EI-TM)	"The degree to which top management understands the importance of the IS function and the extent to which it is involved in IS activities" (Torkzadeh and Doll, 1999, p.329)	The degree to which top management understands the importance of BIM and the extent to which it is involved in BIM activities

6.3 CONCEPTUALISATION OF THE FOCAL CONSTRUCTS

Building on the framework set out in Figure 6.2, this section discusses the conceptualisation of the focal constructs, namely Perceived Extent of Use and Actual Extent of Assimilation. As shown in Figure 6.4, hypotheses are developed to explain the relationships between these constructs.

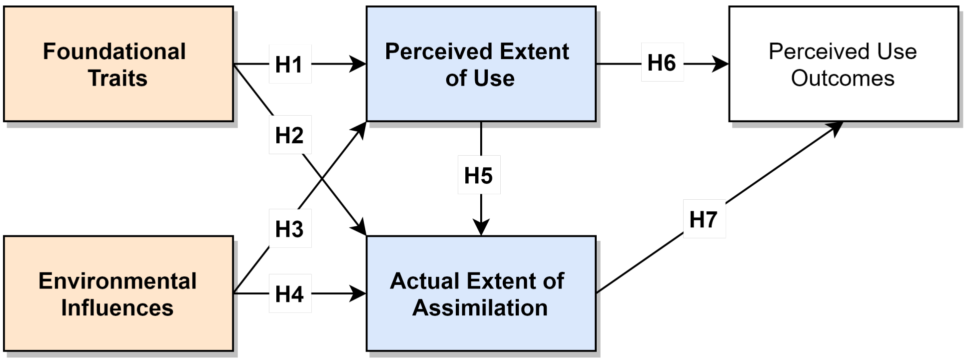


Figure 6.4 Focal constructs: Perceived Extent of Use and Actual Extent of Assimilation

Based on this figure, the following hypotheses have been developed:

Hypothesis 5. *An individual's perceived extent of use of BIM has a direct relationship with their actual extent of assimilation.*

Hypothesis 6. *Perceived Extent of Use (PEU) has a direct relationship with Perceived Use Outcomes (PO).*

Hypothesis 7. *Actual Extent of Assimilation (EA) has a direct relationship with Perceived Use Outcomes (PO).*

6.3.1 PERCEIVED EXTENT OF USE

When considering the utilisation of an innovation or system with the existing theoretical models and frameworks, it tends to be framed as a dichotomous outcome variable, e.g. Perceived Use. However, notwithstanding the application of such a measure to multifaceted innovations like BIM, this assessment of system use has drawn criticism for its over-simplification. For example, Petter et al. (2008) argue that it is more appropriate to interpret system utilisation as a continuum between “use” and “non-use”. The authors note that this reading also stands regardless of voluntariness, stating that use is “rarely ever either totally voluntary or totally mandatory” (Petter, DeLone, and Mclean, 2008, p.256). Moreover, they call on researchers to consider applying alternative measures to capture this variability by considering using measures that account for intensity and extent of use. To this end, this study deals with Perceived Extent of Use as the independent construct. This complements earlier research by Fichman (2000), who presented a series of measures for organisational innovativeness, pertaining to what he later termed as the ‘quantity’ of an innovation (Fichman, 2004). These include infusion, routinisation, and assimilation.

Measures pertaining to a spectrum of adoption have already been employed in BIM adoption studies. For example, Cao et al. (2014a) measured Extent of BIM Adoption using an aggregated index on BIM usage across 13 application areas spanning design and construction. In a later study, Cao et al. (2016) operationalised Level of BIM Adoption as a single-item construct, using a three-scale measure based on BIM levels. In their schema, Level One captured 3D and 4D uses at the *model-based visualisation level*, Level Two, represented 3D and 4D uses at the *model-based analysis level* by incorporating parametric capabilities, and Level Three, captured the collaborative qualities of BIM at the so-called *model-based integration level* Gledson and Greenwood (2017) apply a more granular lens to the extent of BIM use by studying the extent of 4D-BIM use in method planning and time scheduling. The authors applied a progressive scale of activity to 4D-BIM, asking respondents to identify where it was used to identify, assess, plan, communicate, or manage method planning and time scheduling. Therefore, in line with these studies and the justification for the framework, the operationalisation of the construct should endeavour to include measures which capture a multidimensional view of BIM use. Finally, the construct is conceptualised using the term *Perceived* to highlight that the fact it is self-reported by respondents. This will provide the ability to assess it against actual system use (Jeyaraj, Rottman, and Lacity, 2006).

6.3.2 Actual Extent of Assimilation

The consideration of Assimilation as a construct has generally been neglected in innovation adoption literature, particularly when approaching from a micro-perspective (Liu et al., 2011; Enkel et al., 2017). Rather, most of the scholarly attention has been restricted to considering assimilation from an organisational perspective (e.g. Fichman and Kemerer, 1997; Cho and Kim, 2002; Hossain et al., 2011). However, scholars such as Cohen and Levinthal (1990) and, more latterly, Liu et al. (2011) argue that assimilation should be approached from a multi-level perspective as assimilation occurs at the micro- and meso-levels simultaneously. This is because the concepts of individual and organisational absorptive capacity (see Section 2.2.3) are interlinked (Cohen and Levinthal, 1990).

As discussed in Section 2.2.3, assimilation from an organisational perspective relates to the stepped process from initial awareness to routinisation and infusion (Cooper and Zmud, 1990; Bajwa, Garcia, and Mooney, 2004). Therefore, as with Perceived Extent of Use, this construct should use measures which place the respondent on a continuum which in this instance pertains to the extent of assimilation. Furthermore, the measures should ascertain to what extent the individual is actually using BIM without relying on self-reporting metrics. This is critical as understanding actual use versus perceived use allows adopters to evaluate their decisions and implementation processes with respect to the extent of their investment (Jeyaraj, Rottman, and Lacity, 2006). The development of the construct and the measures used to capture the Actual Extent of Assimilation will be discussed in Chapter SEVEN.

6.3.3 Operational Definitions

A summary of the conceptual and operational definitions for each of the constructs are presented in Table 6.2. As the Actual Extent of Assimilation construct is novel, an operational definition based on the discussions presented within this chapter is provided.

Table 6.2 Conceptual and operational definitions of the focal constructs

Focal Construct	Conceptual Definition	Operational Definition
Perceived Extent of Use (PEU)	"The amount of use of an innovation by a person or organization. This is a self-report of the frequency of use by the individual or organization" (Jeyaraj, Rottman, and Lacity, 2006)	The perceived amount of use of BIM by a person.
Actual Extent of Assimilation (EA)	*Defined for this study.*	The extent to which a person has progressed through stages of innovation assimilation, from initial awareness of BIM to the actual routinised application of its principles.

6.4 CONCEPTUALISATION OF THE PERCEIVED USE OUTCOMES

This section introduces and discusses the perceived use outcomes. Two constructs are discussed: Perceived Benefits, which is a multidimensional factor which attempts to capture the key benefits associated with BIM adoption and use, and Behavioural Intent to Continue Use. Figure 6.5 illustrates these relationships.

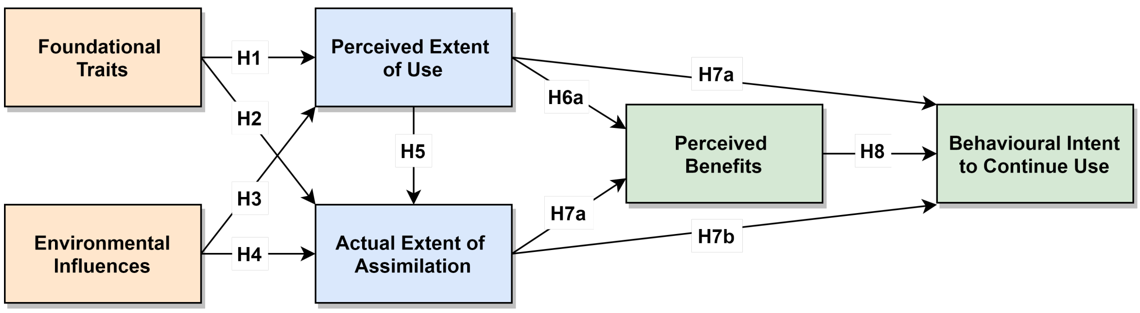


Figure 6.5 Perceived Benefits and Behavioural Intent to Continue Use as the Perceived Use Outcomes

Hypothesis 6a. *There is a direct relationship between perceived extent of use and perceived benefits.*

Hypothesis 6b. *There is a direct relationship between perceived extent of use and behavioural intent to continue use.*

Hypothesis 7a. *There is a direct relationship between actual extent of assimilation and perceived benefits.*

Hypothesis 7b. *There is a direct relationship between actual extent of assimilation and behavioural intent to continue use.*

6.4.1 Perceived Benefits

As embodied by the UK BIM Hypothesis, the UK's BIM discourse is built upon the perceived benefits that could be realised with the effective adoption and use of BIM. Therefore, the ability to measure benefits is key to understanding the success of the BIM discourse. This has led to numerous industry-led tools being developed which attempt to quantify these benefits and align them with maturity assessments where possible. Moreover, industry research has identified strong support for benefits measurement and evaluation, which 92% of survey respondents highlighting that it encourages an increasingly collaborative way of working, amongst other benefits (Kassem et al., 2020). Academic efforts have also attempted to quantify and categorise BIM benefits, either through case studies (e.g. Azhar, 2011; Barlish and Sullivan, 2012) or through literature appraisals (e.g. Ghaffarianhoseini et al., 2017). These studies have highlighted several benefits, such as those relating to technical, knowledge management, standardisation, diversity management, integration, economic, planning and scheduling, building lifecycle assessment, and decision support groups.

However, as the present study focuses on BIM adoption and use at the micro-level, the emphasis on meso-level benefits measurement, such as utilising Key Performance Indicators (e.g. Won and Lee, 2016), Critical Success Factors and Returns on Investment (e.g. Jin et al., 2017) are not applicable. Yet, within established IS adoption theory, Perceived Benefits aren't explicitly defined as a distinct construct. As discussed in Section 5.4.2, adoption consequences are generally not studied, despite calls to the contrary (Jeyaraj, Rottman, and Lacity, 2006).

The Perceived Benefits construct is conceptualised as a second-order construct. By assuming this multidimensional approach, the risk of interpreting BIM as a single tool or application is reduced through the emphasis on multiple qualities, i.e. the principles of BIM are purported to improve Client Satisfaction and Improved Coordination, whereas the use of a BIM modelling tool may improve coordination but will not necessarily affect client satisfaction. Furthermore, as the Perceived Benefits construct is not explicitly grounded in existing theory, developing multiple second-order based on literature may conceptually strengthen the tenet of the first-order construct. The second-order Perceived Benefits construct captures numerous literature-driven constructs, namely Client Satisfaction, Task Productivity, Improved Coordination, Data Accuracy, and Data Reliability. These relationships are illustrated in Figure 6.6.

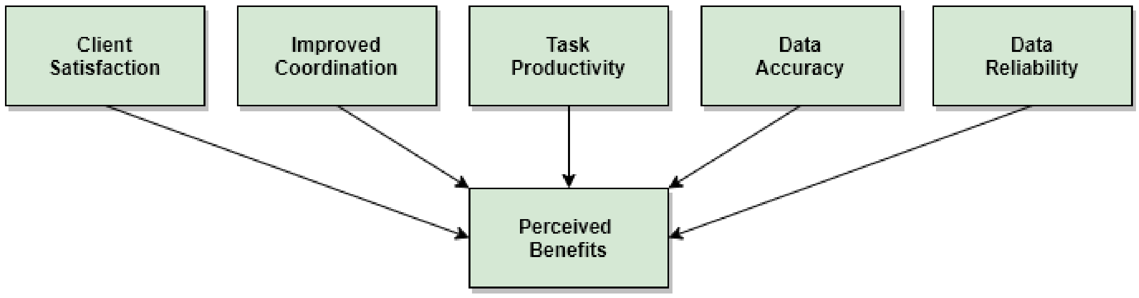


Figure 6.6 Perceived Benefits as a second-order construct

Building on the premise set out by the ISSM, it is suggested a relationship exists between Net Benefits and Intention to Use. Therefore, this relationship is hypothesised as such:

Hypothesis 8. *The perceived benefits have a positive influence on the individual's behavioural Intent to continue use.*

Each of the second-order constructs are conceptualised below.

Client Satisfaction (PB-CS)

When considering Satisfaction as a construct within BIM adoption research, most literature focuses on the satisfaction of the BIM user (e.g. Lee and Yu, 2012; Lee and Yu, 2016; Song et al., 2017; Wang and Song, 2017). However, this construct can easily be conflated with the individual's satisfaction with BIM tools, particularly if their awareness and understanding of BIM is limited. This research instead focuses on Client Satisfaction. The satisfaction of the client is key to the UK's BIM Hypothesis, which follows the principles of Egan and is framed around the role of government as the client (Egan, 1998). Furthermore, the integration of Soft Landings into BIM through the BS 8536 standards (see Appendix A) emphasises the role of Client Satisfaction through auditing processes, such as post-occupancy evaluation. In earlier stages, clients are also becoming generally more involved with decision-making and design through increased levels of visualisation and interaction (Lee and Ha, 2013). Lastly, Eadie et al. (2013a) found clients to be the biggest beneficiaries from effective BIM implementation, therefore highlighting a need to consider their satisfaction as KPIs within benefits measurement (Bryde, Broquetas, and Volm, 2013; McGraw Hill Construction, 2014). Therefore, Client Satisfaction should be considered as a key benefit (Zhou et al., 2017).

Task Productivity (PB-TP)

Within IS-based innovation adoption research, productivity at the micro-level is captured using the Task Productivity construct (Torkzadeh and Doll, 1999), which in turn, is said to contribute to meso-level productivity (Delone and Mclean, 2003; Petter, DeLone, and Mclean, 2008). Productivity is a KPI of industry health (Infrastructure and Projects Authority, 2016; McKinsey Global Institute, 2017). As such, productivity is frequently cited as a metric of BIM implementation success (e.g. Li et al., 2014; Fakhimi et al., 2017; Enshassi, Abuhamra, and Alkilani, 2018). In their investigation into the integration of mobile BIM and AR systems, Chu et al. state that as "the construction industry embraces BIM there is a perception that task productivity will improve in construction" (2018, p.315). Love et al. (2013) found that, when developed to the appropriate level of development[3], asset owners can respond to issues more effectively, thereby improving productivity. Although Fox (2014) highlights a potential gap between hype-driven rhetoric and reality surrounding benefits realisation, Love et al. (2013) note that initial assimilation activities may result in a temporary loss of productivity as users embark on a learning curve. Generally, however, BIM implementation has been shown to improve productivity (e.g. Porwal and Hewage, 2013; Jin et al., 2017). In addition, the NBS National BIM Report identified that 71% and 78% of survey respondents anticipate that BIM and wider

[3]The level of development is now referred to as the level of information need in accordance with ISO 19650.

digitisation will help improve productivity respectively (NBS, 2020). Therefore, Task Productivity is considered as a construct for Perceived Benefits within the present study.

Improved Coordination (PB-IC)

The AECO industry is traditionally characterised by how contractual parties are reticent to interact with each other, creating individual "siloed" work environments in the design and build process (Ciribini, Mastrolembo Ventura, and Paneroni, 2016). The Bew-Richards interpretation of BIM (see Figure 1.3 in Section 1.2.2) was developed to reflect the levels of maturity surrounding project team integration: Level 1 BIM introduced CDE-enabled collaboration through consistent information management practices, which was in turn built on by Level 2 BIM to require the federation of the multiple discipline models in one coordinated environment. Through the 3D visualisation of the environment, spatial coordination is considered one of the most important benefits of BIM adoption (e.g. Hanna, Boodai, and El Asmar, 2013; Boktor, Hanna, and Menassa, 2014; Tsai, Mom, and Hsieh, 2014; Attarzadeh, Nath, and Tiong, 2015; Sun et al., 2015; Bosch-Sijtsema et al., 2017; Nasila and Cloete, 2018, etc.). Furthermore, the key to unlocking the potential of spatial coordination is clash detection. The ability to identify and resolve conflicts between objects prior to work onsite reduces the number of change orders and contractor requests for information, and the need to redo work, thereby contributing to effective waste management from the early design stages when compared to traditional design processes (Attarzadeh, Nath, and Tiong, 2015; Ahn, Kwak, and Suk, 2016; Won and Cheng, 2017). Lastly, the consideration of coordination activities within the conceptual model demonstrates an attempt to capture the interdependencies between individual practitioners, highlighting BIM's role as a systemic innovation. Therefore, Improved Coordination is considered to be a second-order construct for Perceived Benefits.

Data Accuracy (PB-AC)

Within IS-based innovation adoption research, Data Accuracy is often associated with perceived Information Quality(Doll and Torkzadeh, 1988; DeLone and Mclean, 1992; Delone and Mclean, 2003; Gattiker and Goodhue, 2005; Wixom and Todd, 2005). Many of the purported benefits of BIM can be linked to Data Accuracy. Although Love et al. (2011) caution against viewing BIM as the sole solution for error containment, greater accuracy can be linked to the increased reliance on computer-based modelling and data capture, where reliance on direct human input is reduced and design tolerances are made more precise. Through empirical research, BIM has been demonstrated to reduce errors in the design phase (Arayici et al., 2011b; Attarzadeh, Nath, and Tiong, 2015), reduce rework (e.g. Barlish and Sullivan, 2012; Lee, Park, and Won, 2012; Bryde, Broquetas, and Volm, 2013; Jin et al., 2017), and improve data in the FM stages (e.g. Eadie et al., 2013b; Kassem et al., 2015). For example, Charehzehi et al. (2017) found clash detection, which as discussed earlier is one of the hallmarks of BIM functionality, is crucial to achieving design accuracy through the reduction of errors. The resulting reduction in conflicts then also reduces the need for Requests for Information (RFIs) and fewer change orders, resulting in more accurate cost management (Ghaffarianhoseini et al., 2017). Wong et al. (2014) found the use of BIM to also improve cost planning accuracy, as the ability to extract quantities directly from the model environment reduces human error and automates the process of information updates when changes are made to the model. Based on these assertions, Data Accuracy is conceptualised as a second-order construct to Perceived Benefits.

Data Reliability (PB-RE)

Similar to Data Accuracy, Data Reliability can pertain to the Information Quality construct within the ISSM (Gattiker and Goodhue, 2005). As the data created and managed through BIM is to be shareable and used throughout the asset's lifecycle for decision-making, the reliability of the data is a crucial consideration, particularly for legacy assets (NBS, 2016a). Early case studies demonstrate that the implementation of BIM can result in "an overall increased reliability of the project budget, program compliance, and delivery schedule" (Eastman et al., 2008, p.294). This is because, unlike traditional linear CAD-based workflows, the BIM process relies on the utilisation of a single source of truth from which all project deliverables are derived; this means even last minute changes to one piece of information are reflected in all corresponding documentation. Furthermore, the reliability of information is critical for collaborative working, to allow other task team members to trust the information they are using to inform their own design. To this end, the level of information need frameworks are used to consistently clarify the extent of expected object information expected at set points, thereby ensuring reliability in the intended use of the data. Moreover, to produce reliable data, the BIM tools and processes (i.e. System Quality) should also be perceived as reliable and trustworthy (Wixom and Todd, 2005; Lee and Yu, 2012; Dowsett and Harty, 2018). Lastly, the concept of reliability is embodied within the NBIMS BIM definition, in which it states BIM is the process of "creating a shared knowledge resource for information about [a facility] forming a reliable basis for decisions during its life cycle" (National Institute of Building Sciences, 2020). Based on these considerations, Data Reliability is provided as the last second-order construct to Perceived Benefits.

6.4.2 Behavioural Intent to Continue Use

Behavioural Intent is a core construct in many of the theoretical models and frameworks discussed in the previous chapter, having stemmed from the study of behavioural change when used in a Theory of Reasoned Action or Planned Behaviour context. Following the emergence of technology acceptance models, Behavioural Intent transitioned into Behavioural Intention to Use, to signify the shift in focus from behaviour to the act of adopting technological artefacts.

Given its prominence in prescribed theory, the construct of Behavioural Intent has been applied several micro-level BIM adoption studies. For example, Howard et al. (2017) found that Social Influence has a strong influence on Behavioural Intent, emphasising the requirement for effective communication channels in the promotion of the BIM discourse (Rogers, 2003). Interestingly, contrary to the tenet promoted by UTAUT, the authors also found Performance Expectancy to not influence Behavioural Intent, indicating that BIM may not be perceived to improve performance. In other studies, Acquah and Oteng (Acquah and Oteng, 2018) found Perceived Usefulness and the individual's Attitude Toward BIM to each influence Behavioural Intent to adopt BIM, whilst Son, Lee Kim (2015) also found Perceived Ease of Use to be a predictor.

However, this approach to Behavioural Intent provides a limited perspective of BIM adoption when considering adoption behaviour in the post-confirmation stage (2003). As discussed in Section 5.4.2, this restricts the focus to innovation acceptance, or intent to use, rather than considering actual adoption, or intent to continue use. Therefore, behavioural intentions are conceptualised within this study as "Behavioural Intent to Continue Use".

6.4.3 Operational Definitions

A summary of the conceptual and operational definitions for each of the constructs are presented in Table 6.3. As the Actual Extent of Assimilation construct is novel, an operational definition based on the discussions presented within this chapter is provided.

Table 6.3 Conceptual and operational definitions of the Perceived Use Outcome factors

Factor	Conceptual Definition	Operational Definition
Perceived Benefits (PB)	"The extent to which IS are contributing to the success of individuals, groups, organizations, industries, and nations" (Petter, DeLone, and Mclean, 2008, p.239)	The extent to which BIM is contributing to the perceived success of individuals.
Client Satisfaction (PO-CS)	"The extent to which an application helps the user create value for the firm’s internal or external customers" (Torkzadeh and Doll, 1999, p.329)	The extent to which BIM helps the user create value for the firm’s internal or external clients.
Improved Coordination (PO-IC)	The degree to which information links between interdependent subunits in the business produce a valuable benefit (Gattiker and Goodhue, 2005)	The degree to which object-based coordination activities between interdependent project task team members produce a valuable benefit compared to traditional processes.
Task Productivity (PO-TP)	"The extent to which an application improves the user’s output per unit of time" (Torkzadeh and Doll, 1999, p.329)	The extent to which BIM improves the user’s output per unit of time.
Data Accuracy (PO-AC)	"The user’s perception that the information is correct" (Wixom and Todd, 2005, p.91)	The user’s perception that the information created and managed using BIM is correct.
Data Reliability (PO-RE)	The user’s perception that the information is reliable (adapted from Wixom and Todd, 2005)	The user’s perception that the information created and managed using BIM is reliable.
Behavioural Intent to Continue Use (BI)	"A person’s subjective probability that he will perform some behavior” (Fishbein and Ajzen, 1975, p.288)	A person’s subjective probability that they will continue to use BIM.

6.5 CONCEPTUALISATION OF MODERATING VARIABLE

One of the most voiced criticisms of traditional technology acceptance models lies in the adoptor's assumed freedom to act without limitation (Venkatesh et al., 2003; Merschbrock and Nordahl-Rolfsen, 2016). This is because this assumption neglects the consideration of innovation adoption within a mandatory context where the initial innovation decision is made at an authoritative level, which is frequently the case when considering innovation adoption within a professional capacity. In an attempt to mitigate the issue, the TAM2 Venkatesh2000a and the UTAUT (Venkatesh et al., 2003) introduced a moderating construct, pertaining to the extent of Voluntariness as conceptualised by Moore and Benbasat (1991).

Despite its inclusion in later theory, the role of Voluntariness on an individual's perception of BIM adoption and assimilation is not well understood in a BIM context. Yet, as the decision to adopt BIM will predominantly reside at the meso-level due to its systemic nature and need for investment and coordinated implementation, the decision to adopt BIM at the micro-level is likely to be authority-led and thus contingent to the primary decision made at organisation-level (Rogers, 2003). In organisations where this is the case, the use of BIM is therefore often mandatory for the individuals. In these circumstances, Howard et al. (2017) found Voluntariness of Use to moderate the relationship between Social Influence and Behavioural Intention to use BIM. Therefore, Voluntariness of Use is included as a moderating variable within the present study. To conceptualise the construct within the context of this work, the following definition is provided: "the degree of freedom individuals [have] in choosing whether to utilize BIM" (Howard, Restrepo, and Chang, 2017, p.111).

Other moderating variables promoted by established theory, such as Gender and Age, are not theorised to have a significant influence on any of the construct relationships discussed in this chapter. This is because BIM is strictly used in a professional capacity and within organisation-driven behavioural contexts, which are perceived to not be subject to influence by Gender or Age-related attributes (Howard, Restrepo, and Chang, 2017).

6.6 Presentation of the Conceptual Model

This chapter has outlined the underlying theoretical framework for the present study. After Fichman (Fichman, 2004), the proposed model has been configured using constructs which have been extensively validated in previous studies and theoretical models. However, as the application of IS-based innovation adoption theory is still an emerging area for empirical research within the BIM domain, the present study has also looked to the seminal work of key IS scholars to inform the construct conceptualisation process.

Figure 6.7 illustrates the conceptual model, based upon the discussions facilitated within this chapter. Whilst it is recognised that the conceptual model can take on a range of configurations using the constructs conceptualised here, the present model has been organically generated using the framework provided in Section 6.1. Based upon the UK's BIM discourse and the theoretical narrative provided within the previous chapter, this framework suggests a linear, causal relationship between the antecedent drivers, BIM use behaviour, and BIM use outcomes in line with IS-based theory. As the model was constructed organically from the framework and the literature, other iterations of the model were not considered for the present study.

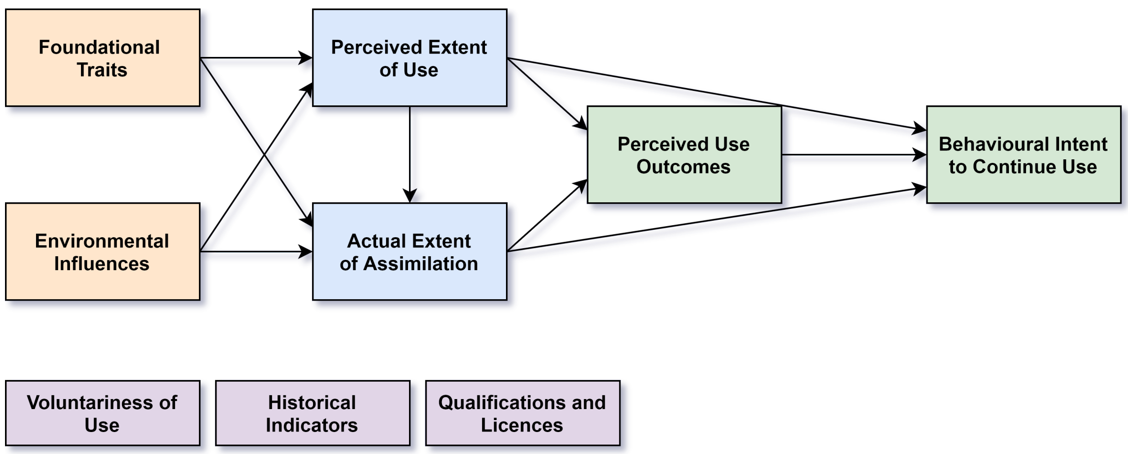


Figure 6.7 BIM Adoption, Assimilation and Utilisation Model (BAAUM)

Therefore, the proposed model, termed here as the BIM Assimilation, Adoption and Utilisation Model (BAAUM), presents a series of hypothesised relationships which shall be investigated in Phase II of the research. Using the terminology promoted by the UBAT,

Figure 6.7 focuses on the relationships between the high-level drivers, whereas the full schematic of the BAAUM breaks the model down into the drivers, factors, and their hypothesised relationships. The full schematic is provided in Figure 6.8 (see next page).

6.7 Application of the BAAUM

The development of the conceptual model allows the hypothesised relationships to be tested and the underlying theory to be accepted or rejected. The BAAUM will therefore be primarily used to inform the development of an instrument through which to measure and analyse the proposed constructs and their relationships. Using the abductive reasoning approach promoted in Chapter THREE, the initial iteration of the BAAUM presented within this chapter will be tested and refined in response to the analysis outcomes. Therefore, this version of the BAAUM should be viewed as a prototype for further testing and refinement, using the conceptual framework presented in Section 6.1 as the theoretical anchor against which to frame future discussions for the relationships between constructs.

Once the BAAUM has been empirically validated, it is anticipated that the model and its underlying framework will contribute to the assessment of current capabilities within industry, which in turn can inform policy generation and improvement. Potential applications for an empirically validated BAAUM will be discussed in Chapter NINE.

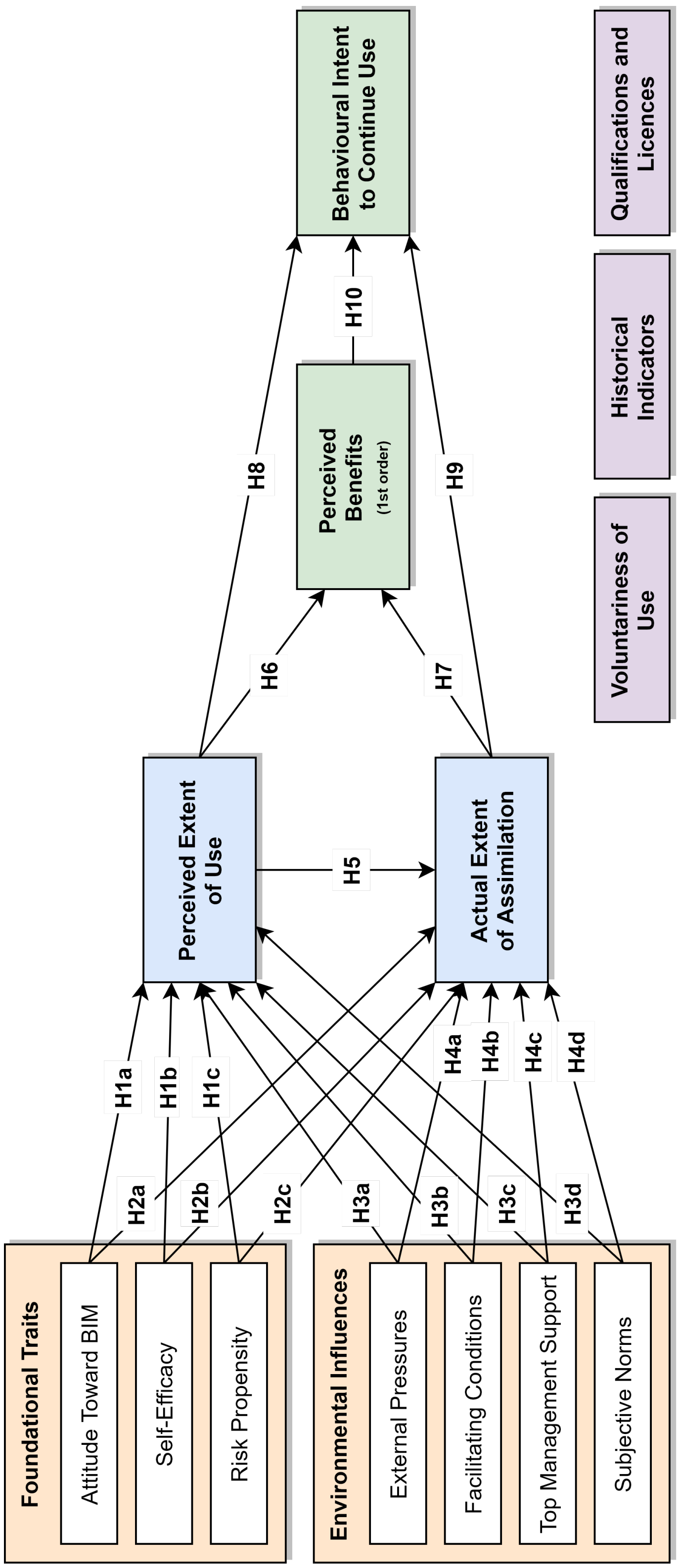


Figure 6.8 Types of question survey and distribution methods, adapted from Bryman (2016) and Saunders et al. (2016)

6.8 Concluding Remarks

Chapter SIX has developed and presented a BIM Assimilation, Adoption and Utilisation Model (BAAUM) as the conceptual framework for the study. In response to the narrative constructed in the previous chapter, the proposed model is based on the critical review of the most common IS-based theoretical models and frameworks that have been used in BIM adoption literature to date. This chapter has progressed this discussion by considering a comprehensive set of drivers and factors to be integrated as constructs within the BAAUM.

The BAAUM presents a mutlilevel perspective of BIM adoption and assimilation by aligning macro-level relationships with those at the micro-level. In a novel approach, the underlying framework for the model is predicated on the UK's Level 2 BIM Hypothesis, thereby grounding the theoretical discussions and drawing on real-world policy to inform the model's construction. The model also considers the role of assimilation as a conceptually distinct construct within the model, which is theorised to influence post-adoption and continuance behaviour.

In summary, a total of ten hypotheses have been developed to empirically test the BAAUM. Chapter SEVEN will therefore develop the data collection and analysis methods with a view to conducting an in-depth empirical investigation into BIM adoption, assimilation, and utilisation using the conceptual model presented here.

CHAPTER SEVEN

PHASE II: DESCRIPTIVE DATA COLLECTION AND PRELIMINARY ANALYSIS

The chapter will use the methodological framing presented in Chapter THREE and the theoretical discussions in Chapter SIX to develop the questionnaire survey instrument for Phase II of this research study. It will first provide an overview of the instrument development process by exploring the operationalisation of each of the constructs presented in the BIM Adoption, Assimilation and Utilisation Model (BAAUM). The chapter will then discuss the empirical data collection and initial data screening procedures. The descriptive statistics for the demographic data are then presented, in addition to a preliminary analysis of the factors. Lastly, the chapter concludes with a review of the two prevailing Structural Equation Modelling (SEM) techniques and presents the case for applying a Partial Least Squares SEM approach.

7.1 INSTRUMENT DEVELOPMENT

The instrument development process involves translating the conceptual framework's constructs into a practical instrument from which robust, reliable data can be collected and analysed. Chapter THREE developed the background for a quantitative study, at which it was decided that the research would employ a cross-sectional approach using a questionnaire survey with mixed internet-based administration modes. As supported by the literature review, this decision aligns with the methods employed within general technology adoption and IS research (e.g. Venkatesh and Davis, 2000; Venkatesh et al., 2003; Bhattacherjee et al., 2015, etc.) and within previous BIM adoption studies (e.g. Cao, Li, and Wang, 2014b; Xu, Feng, and Li, 2014; Eadie et al., 2015; Son, Lee, and Kim, 2015; Cao et al., 2016; Gledson and Greenwood, 2017; Wang and Song, 2017, etc.). Therefore, the research instrument employed in this study phase is an online questionnaire survey.

This section introduces the operational measures for each construct. The final instrument, as sent to participants, is provided in Appendix D.

7.1.1 Operationalisation of the Latent Constructs

Unlike attributes typically measured within the physical sciences, constructs developed within social science settings attempt to capture complex, abstract phenomena which cannot be directly observed using a single, accurate measure (Bryman, 2016). Rather, such factors are theoretical in nature and need to be operationalised. Operationalisation represents the process of translating these abstract constructs into empirical determinants which appropriately capture and reflect the underlying latent factor. In practical terms, this is conducted by using observed, or directly measured, variables as multi-item indicators to infer a "true" representation of the construct within a mathematical model (Hair et al., 2014a; Lowry and Gaskin, 2014; Bryman, 2016).

However, given its abstract nature, latent factors are at risk of not being captured reliably. Therefore, measures which are well established, and which have been extensively tested in extant literature, are either adopted or adapted for the present study where appropriate for the research context. Moreover, the application of pre-existing measures contributes to the standardisation of research instruments. This responds directly to the criticisms of Moore and Benbasat (1991) who posit the lack of standardisation in IS research has led to the domain suffering from mixed and inconclusive outcomes.

Therefore, where possible, extensively tested measures and scales were used to capture constructs drawn from existing theory and contextualised for BIM adoption. Where measures for factors have not yet been applied specifically within a BIM context or taken exactly as theorised from a prescribed model, the Inter-Nomological Network (INN) database was consulted (Larsen and Bong, 2016). By drawing on existing work from neighbouring arenas as enabled by such a centralised resource, extensively used measures could be applied within a new context, thereby developing further insight into innovation adoption theory whilst preserving content validity. Any existing measures drawn from the INN or text from neighbouring domains were adapted in wording to suit the BIM context. To reduce method bias, different types of measures (e.g. traditional Likert-scale and bipolar Likert-scale) and question types (e.g. slide scale and option select) were employed throughout the questionnaire survey where possible (Saunders, Lewis, and Thornhill, 2016).

Lastly, as a precursor to discussing and choosing an appropriate data analysis method, the type of latent construct was also considered. This describes whether the determinants for the factor are reflective - i.e. the direction of causality is from the factor to its determinant - or whether it is formative - i.e. the direction of causality is from the determinant to the factor (Lowry and Gaskin, 2014). Figure 7.1 illustrates the diagrammatic differences between the two constructs. This delineation is critical as it defines what kind of determinant can be used to measure the construct and therefore what kind of analysis procedure is most appropriate.

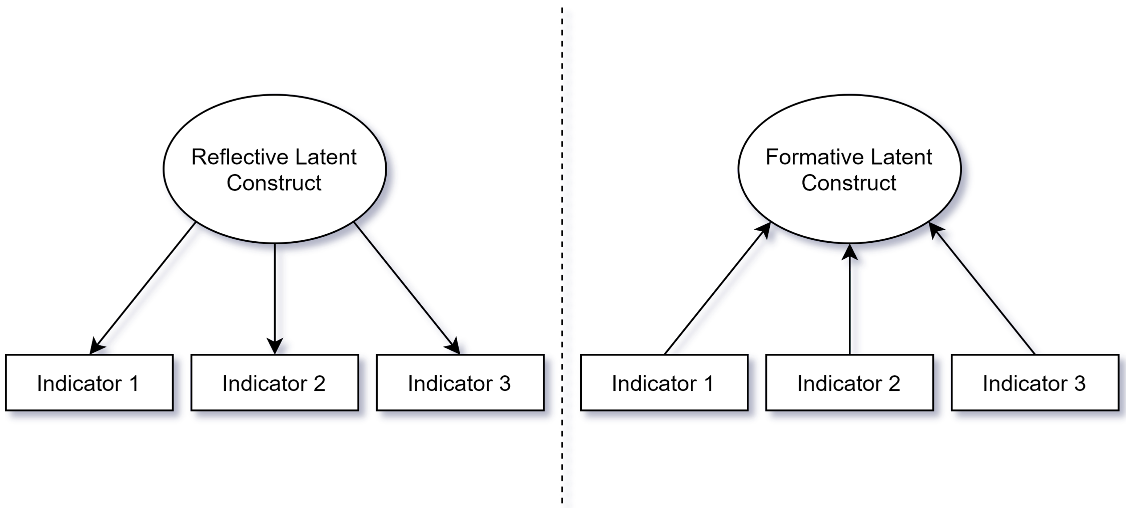


Figure 7.1 Reflective versus formative construct types

Constructs are not inherently reflective or formative (Wilcox, Howell, and Breivik, 2008). However, misspecification of the type of measurement model may lead to improper analysis which in turn may provide erroneous results (Cenfetelli and Bassellier, 2009) and inhibit progress in the field (Jarvis, MacKenzie, and Podsakoff, 2003). Such practice is evidenced by Jarvis et al. (2003) and Petter et al. (2007); both reviews highlighted specification errors across several published articles, with as many as 28% and 30% of formative factors being misspecified as reflective measurement models respectively. Therefore, it is critical to understand the type of measurement model being applied to each construct. The following decision rules are set out in Table 7.1, which will inform the operationalisation of the BAAUM factors.

Table 7.1 Decision rules for determining whether a construct is formative or reflective, after Javis et al. (2003)

Rule	Formative Model	Reflective Model
What is the direction of causality between factor and determinant as implied by the conceptual definition?	Determinant ⟶ Factor.	Factor ⟶ Determinant.
Are the determinants defining characteristics or manifestations of the factor?	Defining characteristics of the factor.	Manifestations of the factor.
Would changes in the factor cause changes in the determinants?	Not necessarily.	Yes.
Are determinants interchangeable?	Not necessarily.	Yes.
Should determinants have similar content?	Not necessarily.	Yes.
Would dropping one of the determinants alter the conceptual domain of the factor?	Likely.	No.
Should determinants covary?	Not necessarily.	Yes.
Should a change in one determinant be associated with changes in other determinants?	Not necessarily.	Yes.
Are the determinants expected to have the same antecedents and consequences?	No.	Yes.

Note: "Not necessarily" indicates that a rule may apply for a formative model, but it isn't as rigid as it for a reflective model

7.1.2 Operational Measures

Using the conceptual and operational definitions provided in the previous chapter, the following tables present the measures used for each of the constructs within the BAAUM. Notably, most reflective constructs employ a close-ended, five-point Likert scale. The Likert scale is a robust scale, appraised by many for its straightforwardness and practicality in use (Bryman, 2016). As such, it is the favoured scale of many when studying the adoption of IS-based innovations (e.g. Moore and Benbasat, 1991; Venkatesh et al., 2003).

Accordingly, Table 7.2 presents the measures used for the Foundational Trait constructs. The reflective Attitude Toward BIM (AT) determinants are presented on a five-point bipolar

Likert scale and adapted from instruments developed by Taylor and Todd (1995) and Venkatesh et al. (2003). The terminology is amended for a BIM adoption context after Howard et al. (2017). Self-Efficacy uses six reflective measures to capture the individual's own perception of their work-related knowledge and skills. The items, originally developed by Riggs et al. (1994) and adapted by Venkatesh et al. (2003) for use within the UTAUT, are presented on a five-point Likert scale, ranging from *Strongly Disagree* to *Strongly Agree*. Three of these items are reverse coded and are noted as such. Lastly, Risk Propensity (RP) is a formative construct, measured by four determinants on a five-point bipolar Likert Scale. The determinants are borrowed verbatim from Lefebvre and Lefebvre (1996).

Table 7.2 Operationalisation of the multi-item Foundational Trait factors

	Determinant / Measure	Type
AT01	Using BIM is a bad idea ⟺ Using BIM is a good idea	Reflective
AT02	I dislike the idea of using BIM ⟺ I like the idea of using BIM	
AT03	Using BIM is a foolish idea ⟺ Using BIM is a wise idea	
RP01	Low-risk projects ⟺ High-risk projects	Formative
RP02	Moderation reaction to change ⟺ Aggressive reaction to change	
RP03	Following competitors ⟺ Before Competitors	
RP04	Time tested methods ⟺ Innovation	
SE01	I have all the skills needed to perform my job very well.	Reflective
SE02r	My future in this job is limited because of my lack of skills.	
SE03	I have confidence in my ability to do my job.	
SE04r	There are some tasks required by my job that I cannot do well.	
SE05	I am very proud of my job skill and abilities.	
SE06r	Most people in my line of work can do this job better than I can.	

Note: "r" denotes reverse-coded item.

Table 7.3 presents the determinants for the four multi-item Environmental Influence factors. External Pressures (EP) has three formative determinants, which focus on governmental, competitor, and client pressures. These determinants have been adapted from the measures used Liang et al (2007) to capture coercive and normative pressures within a single construct. All items are measured using a five-point Likert scale which ranges from *Very Low* to *Very High*. The second factor, Facilitating Conditions (FC), is a formative factor

Table 7.3 Operationalisation of the multi-item Environmental Influence factors

	Determinant / Measure	Type
EP01	Please indicate the extent to which the government's promotion of BIM influences you to use it.	Formative
EP02	Please indicate the extent to which competitive conditions influences you to use BIM.	
EP03	Please indicate the extent to which clients want you to use BIM.	
FC01	I have the resources necessary to use BIM.	Formative
FC02	I have the knowledge and skill necessary to use BIM.	
FC03r	BIM tools and processes are not compatible with the tools and processes I use.	
FC04	A specific person (or group) is available for assistance with difficulties.	
SN01A	My co-workers think that I should use BIM.	Formative
SN02A	My boss thinks that I should use BIM.	
SN03A	Senior management thinks I should use BIM.	
SN01B	Generally speaking, I respect and put in practice my co-workers' decisions.	
SN02B	Generally speaking, I accept and carry out my boss's decision even though it is different from mine.	
SN03B	Generally speaking, I try to follow senior management's policy and intention.	
TM01	Top management actively engages in selecting the vendor for BIM tools and consulting firm.	Reflective
TM02	Top management actively engages in recruiting the personnel needed for implementing and operating BIM.	
TM03	Top management is much concerned with the performance of BIM.	
TM04	Top management makes an effort to provide stable and sufficient funding for BIM implementation and operation.	
TM05	Top management emphasises managing and controlling the processes of BIM and operation effectively.	

Note: "r" denotes reverse-coded item.

measured by four determinants, as developed by Venkatesh et al. (2003) and rephrased for the BIM context following Howard et al. (2017). In line with its original use, FC03 is reverse-coded. The third factor, Subject Norms (SN), is presented as a function of normative beliefs (*nb*) and motivation to comply (*mc*), after Fishbein and Ajzen (1975; 2002). In other words, the individual's normative belief about a party is weighted by their tendency to comply with that party's wishes, as follows:

$$SN = nb \cdot mc \tag{7.1}$$

The Likert-scale determinants are adapted from the normative structure measures developed by Taylor and Todd (1995) but uses the peer groups identified by Gallivan (2001) to contextualise the construct to the workplace. Lastly, the Top Management Support (TM) factor is a reflective construct which uses five Likert-scale determinants adapted from Lee and Kim (1992), as cited in Wang et al. (2006). With the exception of External Pressures as mentioned, all items are measured from *Strongly Disagree* to *Strongly Agree*.

Table 7.4 (see next page) provides the determinants used to measure the multi-item factors used to capture the constructs relating to Perceived Use Outcomes. All items use five-point Likert scales ranging from *Strongly Disagree* to *Strongly Agree*. The first-order factor, Perceived Benefits (PB), is captured using five second-order factors which are each measured using a series of reflective items. These determinants are derived from the work of Moore and Benbasat (1991), Torkzadeh and Doll (1999), Gattiker and Goodhue (2005), and Wixom and Todd (2005). Finally, the Behavioural Intent to Continue Use (BI) factor is a distinct, reflective construct which was validated as part of the UTAUT conception (Venkatesh et al., 2003). All determinants have been adjusted to suit the BIM context. Moreover, as reflective items are similar in content when measuring the same underlying factor, all determinants intending to measure Perceived Use Outcomes were randomly mixed over two questions during the survey deployment to prevent respondent fatigue.

Table 7.4 Operationalisation of the multi-item Perceived Use Outcome factors

	Determinant / Measure	Type
CS01	Using BIM and Information Management processes helps me meet client needs.	Reflective
CS02	Using BIM and Information Management processes improves client satisfaction.	
CS03	Using BIM and Information Management processes improves service to the client.	
IC01	Using BIM and Information Management processes helps me adjust to changing conditions within project teams.	Reflective
IC02	Using BIM and Information Management processes has improved my coordination with other project team members.	
IC03	Using BIM and Information Management processes makes me aware of important information from other project team members.	
IC04	Using BIM and Information Management processes helps me synchronize with other project team members.	
TP01	Using BIM and Information Management processes saves my time.	Reflective
TP02	Using BIM and Information Management processes allows me to accomplish more work than would otherwise be possible.	
TP03r	Using BIM and Information Management processes decreases my productivity.	
AC01r	The information from BIM applications and processes has numerous accuracy problems that make it difficult for me to do my job.	Reflective
AC02	The information that BIM tools and processes provides to me is accurate.	
AC03	The data I receive from BIM tools and processes is true.	
AC04	BIM data that I use or would like to use are accurate enough for my purposes.	
RE01	The data that BIM provides is exactly what I need to carry out my tasks.	Reflective
RE02r	It is difficult for me to do my job effectively because some of the data I need is missing from the BIM applications and processes.	
RE03	BIM provides the right data to meet my needs.	
RE04r	The data accessible from BIM applications and processes lacks critical information that would be useful to me.	
BI01	I predict I would continue using BIM.	Reflective
BI02r	I do not intend to continue using BIM.	
BI03	I plan to continue using BIM.	

Note: "r" denotes reverse-coded item.

To operationalise the Perceived Extent of Use construct, three formative measures were developed to assess the perceived amount of use of BIM by a person. Firstly, following Cao et al. (2016) in their operationalisation of the Level of BIM Adoption construct, the measures employed in this study were developed based on maturity levels. To ground the work within a UK context, these were aligned to those defined by the UK BIM Task

Group - refer to Figure 1.3 for the Bew-Richards maturity index. Following the definitions developed by the initial BIM strategy (BIM Industry Working Group, 2011), these levels are outlined below:

- **Level 0** describes unmanaged CAD with paper-based data exchange mechanisms.
- **Level 1** describes managed CAD in 2D or 3D formats, underpinned by BS 1192 and with a collaboration tool as the CDE.
- **Level 2** describes a managed 3D model which is federated within a shared space with other 3D models. The 3D model has data attached and may use 4D and 5D processes.
- **Level 3** describes a fully open process with data integration and managed by a collaborative model server.

For the purposes of quantitative analysis, the four progressive levels were scored as 0, 1, 2, and 3 respectively. Notably, the measure probes the respondent's *business-as-usual* level of BIM use in an attempt to capture typical working habits. This is in contrast to questions employed by the NBS National BIM Surveys which asks respondents to provide the highest level achieved to date (e.g. NBS, 2019). In an attempt to fully capture the Perceived Extent of Use factor, respondents were also asked to rate their overall perceived BIM competency using a five-point Likert-scale determinant, ranging from *Very confident* to *Not at all confident*. Lastly, as the UK's BIM maturity index is built on the application of standards, a summated score was developed to assess the individual's perceived competency in these standards. The scale ranged from 0 to 10 for each standard and a total score was calculated to represent total perceived competency in BIM standards.

The three formative measures are presented in Table 7.5. Within the social sciences, self-reported measures of innovation usage such as those outlined in Table 7.5 are generally unfavourable as they can introduce recall bias into the research approach (Jeyaraj, Rottman, and Lacity, 2006). However, as the goal of this research is to better understand the potential gap between perceived and actual use, the self-reported measures are integral to the research design. Furthermore, as seen in Table 7.5, a dummy standard (BS EN 15978: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method) was included to provide further insight into the self-reporting nature of the construct. However, this standard was used for descriptive purposes only and not included in the calculation of the total score, nor in further analysis.

Table 7.5 Operationalisation of the multi-item Perceived Extent of Use factors

	Determinant / Measure			Type
PEU01	Which maturity level do you consider to be your business-as-usual?			Formative
PEU02	How confident are you in your overall competency in BIM?			
PEU03	Please rate your competency in each of the following standards from 0 to 10.			
	BS1192+A2	*BS1192-4*	*BS 8536-1*	
	PAS 1192-2	*PAS 1192-5*	*BS 8536-2*	
	PAS 1192-3	*PAS 1192-6*	*BS 15978**	

* = Dummy standard used for the descriptive analysis.

Table 7.6 (see next page) presents the measures used for the Actual Extent of Assimilation factor. As described in Section 6.3.2, Actual Extent of Assimilation describes a continuum of assimilation activities contextualised to the micro-level using the competency framework developed by Succar et al. (2013). For this reason, the measures developed in the operationalisation of the construct are built around Domain Competencies (i.e. professional abilities) and Execution Competencies (i.e. abilities in using tools and techniques). For more information on competency tiers and sets, see the BIM Framework portal (BIMe Initiative, 2020a) and Succar et al. (2013).

Table 7.6 Operationalisation of Actual Extent of Assimilation

	Determinant / Measure	Type
CDE	**Which of the following statements best describe how you interact with a Common Data Environment (CDE)?**	Dichotomous
CDE1	I exchange digital information within a CDE.	
CDE2	I manage digital information within a CDE.	
CDE3	I receive and review digital information created by others in a CDE.	
CDE4	I create digital information with embedded or associated attributes in a CDE.	
ACT	**Which of the following activities are you involved with?**	Dichotomous
ACT1	Organising information using a classification system.	
ACT2	Resolving issues using clash detection and 3D coordination.	
ACT3	Participating in discipline model reviews.	
ACT4	Using visualisation as a design communication tool.	
ACT5	Validating non-graphical datasets.	
ACT6	Generating non-proprietary file formats for exchange purposes.	
ACT7	Producing BIM objects to a standard.	
ACT8	Sourcing BIM objects from a library.	
ACT9	Producing information for use within an AIM	
ACT10	Adhering to digital security strategies/protocols	
FORM	**Which of the following delivery formats do you typically interact with on a project?**	Dichotomous
FORM1	Individual 3D digital design or construction models with embedded or linked attributes.	
FORM2	Federated 3D models.	
FORM3	COBie datasets.	
FORM4	IFC files.	
FORM5	4D time simulated models.	
FORM6	5D costs for model attributes.	
FORM7	6D "as-built" model with operational data.	
FORM8	2D information, created from scratch (e.g. on CAD software).	
FORM9	2D information generated from a 3D model.	
FORM10	Design analysis outputs.	
FORM11	Simulations and visualisations.	

For the purposes of this study, the Actual Extent of Assimilation was broken down into 25 dichotomous determinants across three key areas: information use within a CDE, BIM-related activities, and BIM-related information formats. The CDE answer categories were drawn from the HS2 Supply Chain BIM Upskilling Study (Mace, 2014) which will enable the direct comparison of results. The BIM-related information formats were derived from a number of sources, including the HS2 study (Mace, 2014), the BIM standards (British Standards Institution, 2013; British Standards Institution, 2014a; British Standards Institution, 2014b), and the National BIM Reports (NBS, 2020).

Finally, the questionnaire survey also asked questions aimed to gather demographic and BIM awareness data, in addition to the data required for the moderating factor, Voluntariness of Use. All measures were designed to gather nominal data and will be presented as part of the descriptive analyses in Sections 7.4 and 7.5.

7.1.3 Pilot Study

Prior to the administration of the questionnaire, the instrument was validated using a pilot study with four participants. This included validation of the logic and ordering of the questions, in addition to exercising quality assurance for the contents. A small number of comments and suggestions were received from the pilot study participants. These largely concerned clarification and rewording, whereas very little comment was made regarding the questions or structure. As no suggestions were made to alter the fundamental structure of the instrument, the responses collected for the pilot study from practitioners were collated within the final study. Those collected from non-practitioners, such as education providers, were discarded as they were not considered to be part of the remit for the target population. One participant recommended to section the survey to allow respondents a degree of autonomy in whether they opted to complete the full, longer survey. This will be discussed in the following section.

7.1.4 Instrument Structure and Logic

Figure 7.2 presents the instrument structure. The figure illustrates that there are ten key question types: Use Demographics / Voluntariness of Use (six questions), Environmental

Influences (four questions), BIM Awareness (five questions), Perceived Extent of Use (five questions), Individual Assimilation (ten questions), Perceived Outcomes / Behavioural Intention (two questions), Foundational Traits (three questions), Organisational Demographics (five questions), and Individual Demographics (six questions). In total, the instrument contained 46 questions (see Appendix D). This can be considered as a relatively long questionnaire; however actions were taken to minimise fatigue and to section the survey. For example, an option was provided to participants to save their position in the survey and continue later if they wished. Moreover, based on the feedback during the pilot study, a gateway question was provided, which prompted respondents to either answer further question or to answer the base questions only. The base questions and gateway-enabled logic is shown in Figure 7.2.

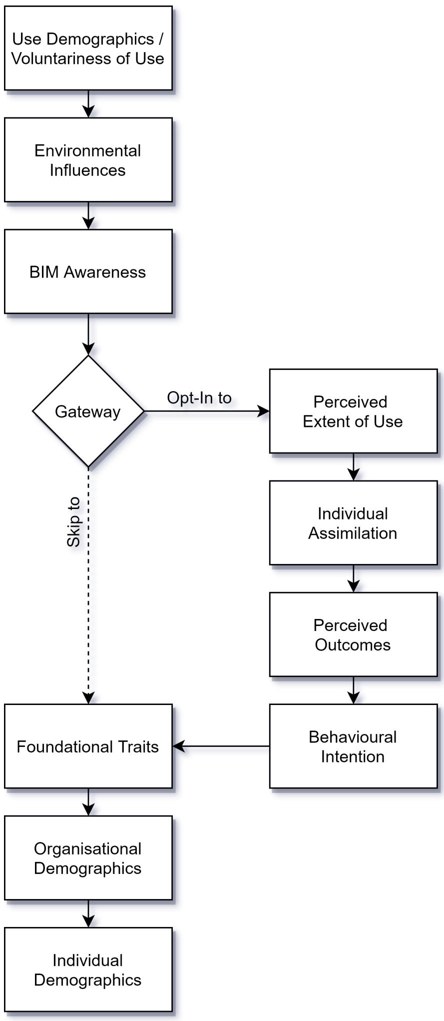


Figure 7.2 Instrument structure and logic for Phase II questionnaire survey

7.2 EMPIRICAL DATA COLLECTION

The data collection portion of the study concerns the actual administration of the developed instrument to an identified audience. This section will cover the procedures and issues which arose during the empirical data collection activities.

7.2.1 TARGET POPULATION AND SAMPLING STRATEGY

An essential element to provide quality assurance and methodological robustness to a questionnaire survey is to construct a comprehensive sampling strategy. In contrast to the role of a census which measures an entire population of interest, sampling concerns itself with estimating characteristics of the population (*N*) through a calculated selection of individual units of analysis or cases (*n*) (Trobia, 2011; Bryman, 2016). Sampling is employed when it is either impracticable for an entire population to be surveyed, or time or budget constraints prevent the researcher from surveying the entire population (Saunders, Lewis, and Thornhill, 2016).

The decision on which sampling strategy to use is first limited to whether a probability or nonprobability technique would be more appropriate for use within the present study. The former ensures that every unit within the population has a chance of randomised selection, whilst the latter is a method which eliminates units from having a chance to being selected. The choice of which to employ is grounded within the boundaries and limitations set by the target population and whether an accurate sampling frame can be constructed.

The target population for the present study is the UK's AECO sector. However, this provides challenges: as briefly discussed in Chapter ONE, there is currently no metric to measure the exact number of practitioners employed within the UK's AECO sector. Whilst employment and productivity statistics produced by the Government are regularly updated for its construction industry each quarter, a similar facility does not exist for consultants and other actors outside the precinct of construction.

Consideration was however given to the utilisation of probability sampling techniques by using professional institute databases as a sampling frame from which to draw units and their contact details, such as the approach employed by Gholizadeh et al. (2018). This would provide access to samples who fulfil the desired criteria, i.e. professional industry practitioners. However, this presented the following challenges:

- Whilst a wide variety of professional institutes exist covering a broad spectrum of AECO-based disciplines, it is difficult to assess whether this was representative of the entire sector when viewed as a sampling frame.

- Institute member databases varied from institution to institution regarding the type of information they provided. Contact details varied from personal contacts to generic mailboxes. Some restricted access altogether and were explicitly protected against non-commercial use.

- Practitioners may be members of more than one Institute. For example, an architectural technologist may be a Member of the Chartered Institute of Architectural Technologists whilst also being an Associate Member of the Chartered Institute of Building. This means that the number of practitioners listed within the sampling frame would not be accurate.

- Databases may not be updated regularly.

- Databases were impractical to access, with some providing thousands of contact details but only enabling ten to be viewed at a time.

As no suitable sampling frame could be identified, non-probability sampling techniques were favoured over probability sampling. Following the justification for the sampling technique employed within Phase I of this study, self-selection sampling using online promotion was also utilised here (Saunders, Lewis, and Thornhill, 2016) - see Section 4.3 for further discussion. To maximise the response rate, purposive sampling techniques were also employed. Purposive sampling seeks to produce a nonrandom sample by direct communication with those deemed representative of the target population (Battaglia, 2008). The invitation email sent to prospective respondent is provided in Appendix D. The limitations surrounding the sampling techniques will be discussed in Chapter NINE.

7.2.2 Instrument Administration Procedures

The questionnaire survey instrument was hosted on the QuestionPro web platform under an academic licence and fronted with an ethics statement for informed consent purposes. The tool was chosen for its range of question types and variety of administration methods offered. This is because the QuestionPro platform enabled the survey to be distributed using mixed web-based modes, as discussed in Section 3.3.4. The various methods employed within this study are discussed below:

- Using the platform's inbuilt emailing function, recruitment emails with a customisable link to the questionnaire survey were sent to a list of contacts.
- A share function was enabled on the questionnaire survey to allow respondents to share it to their own network of contacts following completion.
- The link to the questionnaire survey was also shared in various online forums, such as through LinkedIn and Twitter,.
- As the platform could be supported on multiple operating systems, a tablet-supported version was used to collect responses in-person at built environment-based networking events. This method, however, is better suited to shorter surveys.
- A Quick Response (QR) code was generated and shared on social media platforms. The QR code was also printed on business cards and distributed in-person at events to allow respondents to access and complete the survey in their own time - see Appendix D.

Incentives were not offered for completing the questionnaire. The target population considered professional practitioners only and a concern arose surrounding the attraction of unsuitable respondents. An ethical issue was also raised regarding whether incentivising a professional-oriented survey, rather than a survey targeted to the general population, could be considered as swaying responses.

7.3 Preliminary Data Screening

Prior to subjecting the dataset to analysis techniques, a necessary step is to clean the data for input into statistical analysis software. Screening the dataset, such as identifying patterns of missing data and the presence of outliers in both the cases and the variables, allows for issues to be effectively remediated as is appropriate for the intended analysis techniques. This ensures the dataset is reliable and valid for purposes of testing causal theory (Gaskin, 2016). Prior to data screening, 87 responses were received in total, of which 49 opted to answer all questions beyond the gateway identified in Figure 7.2. An evaluation of the achieved sample size and the data collection procedures used will be provided in Chapter NINE.

This section describes the coding and data entry, missing data, and outliers. This study used IBM SPSS and Microsoft Excel to screen the data. The application of filtering devices within the online instrument resulted in untargeted cases, such as individuals who do not currently work in the UK's AECO sector, being immediately discarded.

7.3.1 Drop-Out Analysis

Based on data provided by the QuestionPro platform, the drop-out rate is illustrated in Figure 7.3.

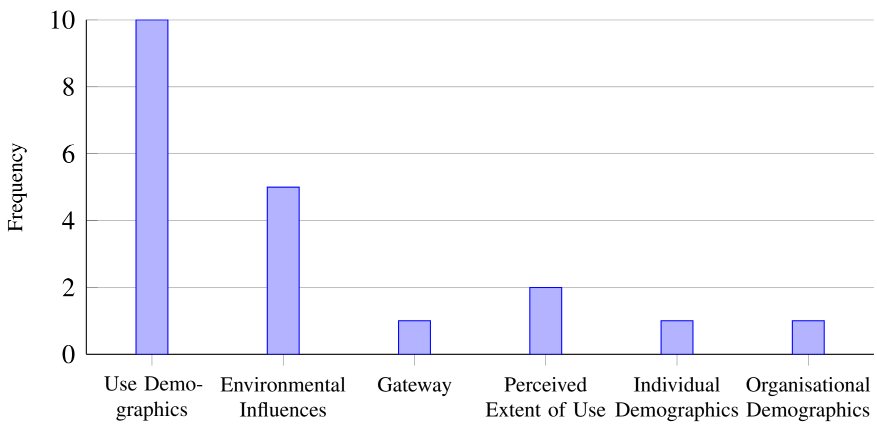


Figure 7.3 Questionnaire survey respondent drop-out analysis

The figure demonstrates that 20 respondents in total exited the questionnaire survey before reaching the conclusion page. Most of the drop-outs (50%) occurred during the initial Use Demographics questions, which suggests that these respondents may have started the survey before finding out they are not eligible, e.g. being based outside of the UK. Only one respondent dropped out at the gateway question. Furthermore, there were no drop-outs identified during the main question types (Individual Assimilation to Foundational Traits in Figure 7.2). Therefore, based on the evidence demonstrated in Figure 7.3, it is suggested that the length of the survey did not impact on response rate.

7.3.2 Coding and Data Entry

The first step in data analysis is the coding and entry of data. This study collected and processed the raw data within Microsoft Excel before exporting the datafile to IBM SPSS for coding. Each item was coded according to the naming standard established when operationalising the constructs in Section 7.1.1. This standard uses a combination of letters and numbers to represent the factor item respectively (e.g. FC01, FC02, FC04). This allows the codes to be easily read and understood during the analyses. As highlighted earlier, reverse-coded items were recoded to align with the scoring system employed within the corresponding construct and tagged with an "r" in the item's name code (e.g. FC03r).

7.3.3 Missing Data

It is extremely rare for research to return complete datasets without experiencing missing data. In dealing with the issue of missing data, Hair et al. (2014a) describe the primary concern as "[identifying] the patterns and relationships underlying the missing data in order to maintain as close as possible the original distribution of values when any remedy is applied" (2014a, p.40). All instances of missing data were considered to be unknown due to a nonresponse by the survey participant and therefore required examination and remediation where possible (Hair et al., 2014a). When assessed, it was found that 87.4% of cases had instances of missing data. Cases with more than 15% missing answers across all applicable questions were considered problematic and were therefore immediately discarded. This translated to 90.8% (N = 79) of total cases being retained when considering all who had completed the core set of questions - see Figure 7.2 for the breakdown of the core and "optional" questions. From the 49 cases which had opted to answer the further set of questions, 14.3% (N = 7) were also screened out based on the 15% threshold for missing data.

Based on the retained cases, the variables were also screened for instances of missing data. Within the opted-in sample, 26% of variables were found to have instances of missing data, although most variables were missing only one or two values. Therefore, following Gaskin (2016), replacement responses to Likert-scale questions were imputed using the median replacement method. As with mean substitution, Hair et al. (2014a) note that this method is preferable when there are relatively low levels of missing data as it provides all cases with complete information. However, it should be noted that the variance of the distribution can be reduced or distorted when mean or median replacement methods are used.

Unlike continuous variables, variables which are based on categorical data cannot be imputed (Gaskin, 2016). Instances of missing data for these variables are instead outlined when discussing demographic data in Section 7.4.1 and Section 7.4.2.

7.3.4 Normality and Outliers

The normality of a variable is described by its skewness and kurtosis (Hair et al., 2014a; Gaskin, 2016). Skewness describes the extent to which the variable's distribution is symmetrical and kurtosis describes the extent to which the distribution is peaked, i.e. weighted towards the middle. As assumptions surrounding the normality of the data influence the choice of data analysis strategy, i.e. whether a parametric or nonparametric strategy is adopted, the skewness and kurtosis values are reported for the relevant constructs within the following sections. Following Hair et al. (2014a), the distribution is considered skewed if the reported skewness value falls outside of the $\pm$ 1 range. Furthermore, when compared to the normal distribution, the distribution can be considered leptokurtic, or peaked, if the kurtosis value is $>$ 1 and platykurtic, or flattened, if the kurtosis value is $<$ -1 (Hair et al., 2017b).

Additionally, the data should also be examined for cases with extreme values that do not correspond with the rest of the data, i.e. outliers. Such instances can have a negative influence on statistical outcomes by altering the distribution, particularly if normal distribution is sought. Therefore, when considering smaller sample sizes ($N \leqslant 80$), Hair et al. (2014a) recommend defining outliers as cases with interval or ratio scaled variables which have a standard deviation of > 2.5. For this reason, the standard deviation from the mean is also reported during the descriptive analyses where relevant.

7.4 Demographic Data

The demographic data of the participants are presented for those who responded as having adopted BIM and opted in to answering the full questionnaire survey (N = 42), and for the total sample of those who answered the core descriptive questions (N = 76). As the total sample need not have considered themselves to have adopted BIM and in lieu of an adequate sampling frame, the total sample acts as a crude proxy for wider representation of industry. The effectiveness and limitations of this approach will be discussed in Chapter NINE. The demographic data looks at the background characteristics of the individual respondents, including their core competencies, and of the organisation they currently work for.

7.4.1 Individual Demographic Data

Tables 7.7 to 7.11 present the participants' characteristics, organised by percentage of respondents with regards to the total sample and compared to the total of the adopters who volunteered to answer the entire questionnaire survey. The participants were asked questions aimed at collecting demographic information surrounding their professional role, including job title, level of role held, level of education, and experience in the role held. Due to BIM being used in a solely professional capacity, an individual's personal attributes, such as age or gender, were not considered to be relevant to the present study and such data was not collected.

The questionnaire survey employed an open response format for the question relating to role title. As suspected, the responses were hugely varied, with little consistency being demonstrated regarding the language used in BIM related roles, which aligns with the findings of Uhm, Lee and Jeon (2017). For the purposes of understanding the demographics of the participants, common themes were identified through the generation of word clouds using the text responses - see Figure 7.4.

Figure 7.4 Wordcloud illustrating prominence of job role terms (total sample)

The themes were used to categorise the identified roles, which are presented as demographic data in Table 7.7. A full list of role titles as provided verbatim and how they have been categorised are provided in Appendix E.

Table 7.7 Respondent distribution by generalised job role

Generalised Job Role	Total Responses		Opted-In Responses	
	Freq.	%	Freq.	%
BIM Consultant	20	26.3	15	35.7
Contractor	2	2.6	0	-
Cost Consultant	3	3.9	0	-
Design Consultant	21	27.6	12	28.6
Director / Chief Role	14	18.4	5	11.9
Intern	1	1.3	0	-
Lead / Head	11	14.5	9	21.4
Project Manager	6	7.9	1	2.4
Senior Associate	2	2.6	1	2.4
Development / Training	1	1.3	1	2.4

Note: Several responses identified more than one job role.

The roles of the respondents are as follows. BIM Consultants make up 26.3% and 35.7% of the total responses and the opted-in responses respectively, which are the largest group for the opted-in sample. The focus on BIM roles is made evident in Figure 7.4. Design Consultants comprise the largest group for the total responses, with 27.6% respondents being involved in the design of a built asset. Design Consultants also formed a large portion of the opted-in sample (28.6%). Conversely, there is no representation from contractors nor cost consultants within the opted-in sample.

To enable answers to be compared at a role-level, the participants were also questioned on their job role with respect to the level within the organisation they are currently working. Table 7.8 reveals that 84.2% of all respondents hold roles which are at the professional level of their organisation or above, with 32.9% (40.5%) and 34.2% (35.7%) holding professional-level and executive or senior management-level roles respectively. This aligns with the frequency of job titles relating to Lead / Head and Director / Chief Role roles, as it does with the size of the *Head* and *Manager* words within Figure 7.4. However, there is no representation from the two lower levels for the opted-in sample, with only one respondent who works in a supervisory capacity.

Table 7.8 Respondent distribution by job level in organisation

Job Level in Organisation	Total Responses		Opted-In Responses	
	Freq.	%	Freq.	%
Executive / Senior Management	26	34.2	15	35.7
Middle Management	13	17.1	5	11.9
Professional	25	32.9	17	40.5
Supervisory	3	3.9	1	2.4
Technical (e.g. Technician)	7	9.2	4	9.5
Operative (e.g. Workforce)	1	1.3	0	-
Graduate	1	1.3	0	-

Next, Table 7.9 provides a breakdown of respondent experience by the number of years working in the UK's AECO sector, for their current organisation, and using BIM in any capacity. Succar et al. (2013) define Historical Indicators as the measurable, verifiable evidence held by the practitioner in relation to their experience. Therefore, in keeping with the study's ongoing contribution to a unified BIM adoption taxonomy, the collective term for the various types of relevant experience is named Historical Indicators.

Table 7.9 Respondent distribution by experience

Historical Indicator	Total Responses		Opted-In Responses	
	Freq.	%	Freq.	%
Years experience working in the UK's AECO sector				
1 Year	8	10.5	0	-
1-2 Years	2	2.6	1	2.4
3-5 Years	10	13.2	7	16.7
6-10 Years	10	13.2	5	11.9
11-25 Years	35	46.1	24	57.1
25 Years	10	13.2	4	9.5
Missing	*1*	*1.3*	*1*	*2.4*
Years experience working for their current organisation				
< 1 Year	10	13.2	4	9.5
1-2 Years	18	23.7	11	26.2
3-5 Years	26	34.2	14	33.3
6-10 Years	8	10.5	3	7.1
11-25 Years	11	14.5	7	16.7
> 25 Years	2	2.6	2	4.8
Missing	*1*	*1.3*	*1*	*2.4*
Years experience using BIM in any capacity				
1 Year	5	6.6	1	2.4
1-2 Years	9	11.8	4	9.5
3-5 Years	12	15.8	8	19.0
6-10 Years	21	27.6	16	38.1
11-25 Years	9	11.8	8	19.0
25 Years	6	7.9	4	9.5
To date, I have not used BIM.	10	13.2	0	-
Missing	*1*	*1.3*	*1*	*2.4*

The results demonstrate a broad range of Historical Indicators across both samples, with the largest portion of respondents aligning in all three categories. In both the opted-in sample and total sample, those having worked in the sector for 11 to 25 years represented the largest group (46.1% and 57.1% respectively). However, only 2.4% of respondents in the opted-in sample had $\leqslant$ 2 years experience, compared to 13.1% within the total sample. Most respondents (71.1% total sample, 69% opted -in sample) also had $\leqslant$ 5 years experience working for their current organisation. Lastly, the largest group of respondents (27.6% total sample, 38.1% opted -in sample) indicated that they have 6 to 10 years of using BIM in any capacity. Interestingly, 7.9% and 9.5% of the responses respectively claim to have been using BIM for over 25 years.

Lastly, Tables 7.10 and 7.11 reports the qualifications and licences for the total and opted-in samples. In addition to Historical Indicators, Succar et al. (2013) identify Qualifications and Licences as a cornerstone of a practitioner's core competency. Qualifications and Licences are comprised of measurable evidence designed to demonstrate a specific element of an individual's competency profile. Within the UK AECO sector, there are several renowned routes to achieve qualification, including undertaking further and higher education, pursuing chartership from a recognised professional institution (e.g. the Chartered Institute of Architectural Technologists (CIAT), the Chartered Institute of Building (CIOB), the Royal Institution of Chartered Surveyors (RICS), the Royal Institution of British Architects (RIBA), etc.), and achieving quality assurance-based certification through standards bodies, such as the BSI. Licences are also a form of badge promoting an individual's capability, often indicating that a standardised test has been passed in order for the candidate to acquire the licence.

Table 7.10 Respondents' distribution by level of education

Highest Level of Education	**Total Responses**		**Opted-In Responses**	
	Freq.	%	Freq.	%
Doctorate (PhD, EngD, etc.)	4	5.3	1	2.40
Postgraduate Degree (MA, MSc, etc.)	37	48.7	22	52.4
Undergraduate Degree (BA, BSc, etc.)	23	30.3	10	23.8
Further Education (HNC, HND, etc.)	7	9.2	7	16.7
Secondary Education (GCSE, A-Level, etc.)	4	5.3	1	2.4
Missing	*1*	*1.3*	*1*	*2.4*

As demonstrated in Table 7.10, 84.3% of all respondents and 78.6% of the opted-in sample hold an undergraduate-level degree or higher. Most of the samples (48.7% of total responses and 52.4% of opted-in responses) hold a postgraduate-level degree, which corresponds to the fact that most respondents work in a professional capacity or higher (Table 7.8).

Finally, it is seen in Table 7.11 that roughly the same percentage of respondents in each group (65.8% of total responses and 64.3% of opted-in responses) hold some form of membership with an industry body or professional organisation. Applying simple text-based analysis to the open-ended responses, it can be seen that the largest group of respondents in both samples hold membership with the Institute for Civil Engineers. Other frequently mentioned memberships include CIOB, the Chartered Institute of Architectural Technologists (CIAT), the Architect's Registration Board (ARB), and RICS. Wordclouds comparing the two groups are provided in Appendix E.

Table 7.11 Descriptive statistics: Qualifications and Licences

Qualification / Licence	**Total Responses**		**Opted-In Responses**	
	Freq.	%	Freq.	%
Are you a member of an industry body or professional organisation?	50	65.8	27	64.3
Have you personally undergone any form of BIM-specific training or third party certification?	42	55.3	34	81.0

Note: Frequency refers to the number of respondents who answered "Yes".

However, there is a clear difference between the portion of those who hold a BIM-specific qualification or certification within the total sample (55.3%) and those within the opted-in sample (81%). This is to be expected to some degree as the total sample includes those who do not consider themselves to use BIM and would therefore not have a need to undertake BIM-specific training. Furthermore, the open-text responses highlight a heterogeneous mix of training, education, and certification schemes across both samples, ranging from BIM-specific postgraduate courses, unspecified in-house training, online webinars and video resources, and institute-led certification schemes. A list of schemes as provided verbatim is provided in Appendix E.

7.4.2 ORGANISATIONAL DEMOGRAPHIC DATA

Table 7.12 to Table 7.14 and Figures present the characteristics of the organisations that the respondents currently work for, organised by percentage of respondents with regards to the total sample and compared to the total of the adopters who volunteered to answer the entire questionnaire survey. The participants were asked questions aimed at collecting demographic information surrounding their professional role, including job title, level of role held, level of education, and experience in the role held. Due to BIM being used in a solely professional capacity, an individual's personal attributes, such as age or gender, were not considered to be relevant to the present study and such data was not collected.

Table 7.12 reports the frequency statistics regarding organisation size. As seen in both samples, respondents are distributed across the various size groups. The largest groups for each sample (30.3% total sample, 33.3% opted -in sample) are those who work for organisations which are > 1000 employees. Furthermore, 48.8% of the total responses and 47.9% of the opted-in responses work for organisations which constitute an SME using the < 250 employee definition, with 9.2% and 11.9% representing micro-SMEs respectively.

Table 7.12 Respondent distribution by size of organisation (no. of employees)

Org. Size	**Total Responses**		**Opted-In Responses**	
	Freq.	%	Freq.	%
1 to 5	7	9.2	5	11.9
6 to 10	0	-	0	-
11 to 25	4	5.3	0	-
26 to 50	11	14.5	6	14.3
51 to 100	11	14.5	5	11.9
101 to 250	4	5.3	4	9.5
251 to 500	6	7.9	2	4.8
501 to 1000	10	13.2	6	14.3
> 1000	23	30.3	14	33.3

Table 7.13 presents the type of organisations based on four overarching categories: manager, designer, contractor or client. Designers comprise the largest portion in both groups (44.8% total sample, 52.4% opted-in sample, whereas the smallest portion is the

client group (7.9% total sample, 2.4% opted-in sample).

Table 7.13 Respondent distribution by organisation type

Org. Type	**Total Responses**		**Opted-In Responses**	
	Freq.	%	Freq.	%
Manager	17	22.4	11	26.2
Designer	34	44.8	22	52.4
Contractor	16	21.1	7	16.7
Client	6	7.9	1	2.4
Missing	*3*	*3.9*	*1*	*2.4*

Table 7.14 presents the breakdown of the project types undertaken by the organisation. Three types of projects are shown: commercial/social, residential, and infrastructure. Within each project type, each respondent was probed about the sort of projects are included, i.e. whether they are public-sector or private sector, or new-build or refurbishment.

Table 7.14 Respondent distribution by project type

Project Type		**Total Responses**		**Opted-In Responses**	
		Freq.	%	Freq.	%
Commercial/Social	Public Sector	42	55.3	25	59.5
	Private Sector	56	73.7	35	83.3
	New-Build	51	67.1	30	71.4
	Refurbishment	38	50.0	23	54.8
Residential	Public Sector	33	43.4	22	52.4
	Private Sector	49	64.5	31	73.8
	New-Build	56	73.7	32	76.2
	Refurbishment	29	38.2	19	45.2
Infrastructure	Public Sector	41	53.9	23	54.8
	Private Sector	39	51.3	23	54.8
	New-Build	42	55.3	23	54.8
	Refurbishment	20	26.3	11	26.2

As shown in the table, the most popular project types are private-sector commercial/social projects and new-build residential (73.7% of respondents each). The most common project type in the opted-in sample is private-sector commercial/social (83.3% of respondents). The least popular project type in both samples are the refurbishment of infrastructure projects (26.3% total sample, 26.2% opted-in sample). Overall, respondents are least involved in refurbishment projects across all three project types.

Next, respondents were asked about where in the UK they conduct work, with the option to select more than one option. This was important as those working on public-sector projects in Scotland have different requirements when compared to those working on public-sector projects in England. Moreover, as discussed in Chapter TWO, the diffusion mechanisms in play across the UK rely on the adoption by public-sector clients in order to trickle out to the private-sector, thereby potentially experiencing a difference given the shift in political agenda. As seen in Figure 7.5, most respondents in both samples work in England, followed by Scotland. The same number of respondents in both sample sets work in Wales and Northern Ireland offices.

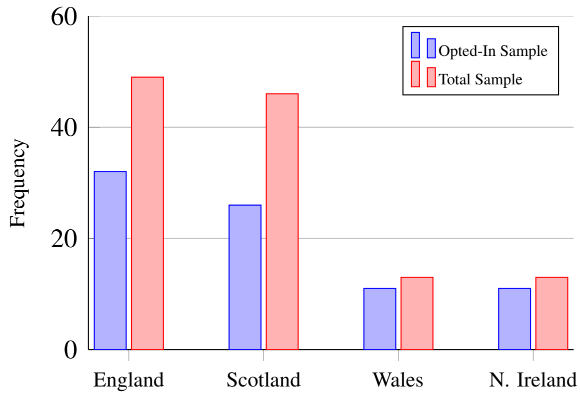


Figure 7.5 Respondent project involvement by project locations

The final organisational demographic question relates to the respondent's involvement by project stage. Again, multiple options could be selected. Given the portion of designers included in both samples, it is not surprising to see that Figure 7.6 reports that most respondents having involvement in the design stage. Based on this design focus, both samples taper out in either direction towards the start and end of a project.The smallest portion of respondents in both samples are involved in the operational stages, which when aligning with the job role and discipline demographics, is to be expected as most of the identified roles are traditionally involved in the capital phase of delivery.

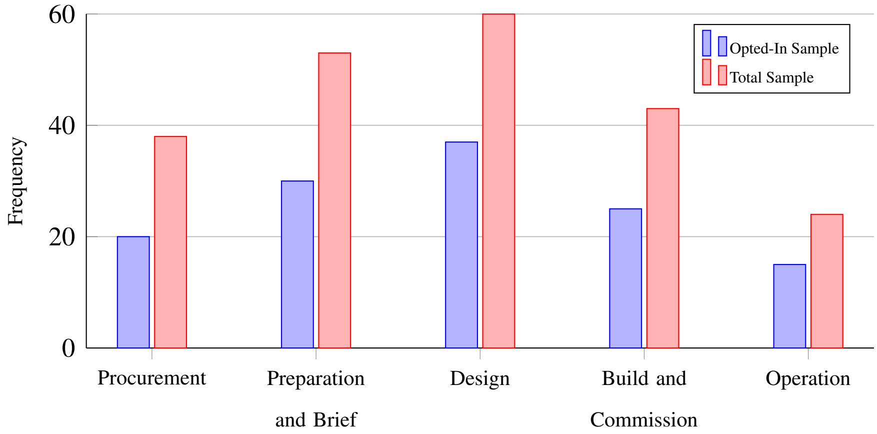


Figure 7.6 Respondent project involvement by project stage

7.5 BIM Adoption and Use

Prior to advanced statistical analysis, it is important to understand the descriptive statistics for each of the constructs within the theoretical model. As a preface to this, some basic adoption data was collected which provides further context to the research. Therefore, this section presents the descriptive analysis for BIM adoption and use, including BIM awareness.

For the purposes of analysis, BIM was defined in accordance with the suite of standards underpinning Level 2 as outlined within the UK's governmental mandate - see Appendix A for a full list of the standards used. This is because the role of the governmental agenda in the UK's BIM discourse, as discussed in Chapter TWO, presents an opportunity for a consistent understanding of BIM through centrally-supported standardisation. Moreover, as the goal of the research was to identify the level of perceived and actual BIM adoption, assimilation and use, a definition for BIM was not provided to respondents prior to their undertaking of the questionnaire survey to prevent skewing of this data.

7.5.1 BIM Awareness

Data were collected looking at the extent of BIM awareness. As established in Chapter ONE, the key strategy documents are Construction 2025, the Government Construction Strategy, and the BIM Strategies within the UK and Scottish governments. Awareness of these strategies is displayed in FIgure 7.7. Notably, all but one respondent indicated that they are aware of the UK Government strategies, with slightly less being aware of the Construction 2025 efficiency targets. Overall, the sample demonstrates a good level of BIM awareness based on the governmental strategies.

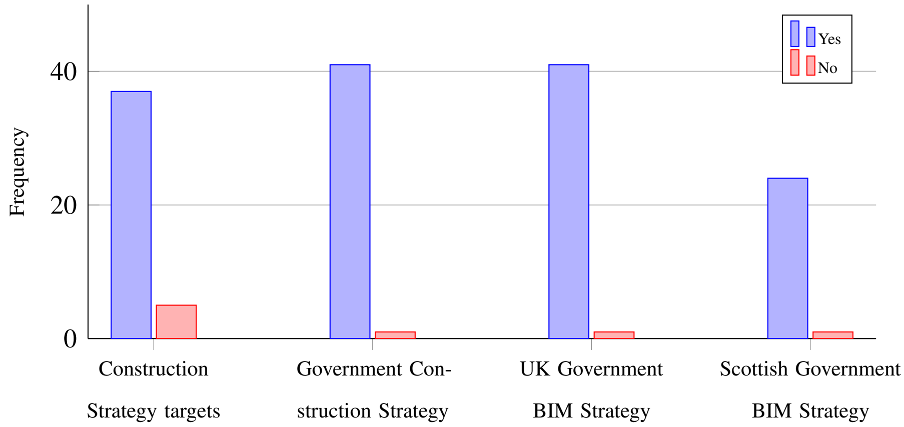


Figure 7.7 BIM strategy awareness by frequency of responses (opted-in sample)

7.5.2 BIM Adoption

Table 7.15 present statistics relating to BIM adoption. Out of the total sample, 71.1% considered themselves to use or work with BIM, with 22.4% stating that they intend to adopt it in the future and 6.6% stating that they have no intentions to adopt it. This reveals that 28.9% of the the total respondents consider themselves to not have adopted BIM. Furthermore, 77.8% of those who consider themselves to use or work with BIM opted into the full question set.

Table 7.15 Descriptive Statistics: Individual BIM Adoption

Individual BIM Adoption	**Total Responses**	
	Frequency	Percent
"Yes, I consider myself to currently use or work with BIM."	54	71.1
"I do not consider myself to have adopted BIM yet, but I intend to adopt it in the future."	17	22.4
"I do not consider myself to have adopted BIM and I have no intentions to adopt it."	5	6.6

Table 7.16 present statistics relating to the BIM adoption of the respondents' organisation.

The data reveals that most individuals consider their organisational to have adopted BIM (69.7% total responses, 83.3% opted-in responses) compared to have not (30.3%, 16.7%). Data is also provided on voluntariness of use. Interestingly, the larger portion within the total sample believe BIM adoption is voluntary (52.6%) compared to the opted-in sample who are more skewed towards perceiving BIM as a mandated required (59.5%). However, Table 7.16 also reports a greater portion of the opted-in sample believe their organisation to have adopted BIM at the strategic level (83.3%) compared to the total sample (69.7%).

Table 7.16 Organisational BIM Use

Organisational BIM Use	**Total Responses**		**Opted-In Responses**	
	Frequency	Percent	Frequency	Percent
"My organisation has adopted BIM"	53	69.7	35	83.3
"My organisation has not adopted BIM"	23	30.3	7	16.7
"BIM adoption is a mandated requirement"	36	47.4	25	59.5
"Individual BIM adoption is voluntary"	40	52.6	17	40.5

7.6 BIM USE BEHAVIOUR

The term "BIM Use Behaviour" is used to collectively describe the Perceived Extent of Use and Actual Extent of Assimilation constructs. Therefore, this section presents the statistics collected for these constructs.

7.6.1 PERCEIVED EXTENT OF USE

The Perceived Extent of Use construct driver is measured with three formative items. The first concerns the perceived business-as-usual BIM Level of the participant. As reported in Table 7.17, most respondents (81.0%) consider themselves to either consider their business-as-usual level to be Level 2 or between Level 1 and 2. Similar to the issue found when reviewing the NBS National BIM Reports, a few respondents identify themselves as having adopted Level 3 BIM, which is not defined beyond its abstract representation within the Bew-Richards wedges. 9.5% of respondents consider themselves to use BIM Level 1 as their business-as-usual. Furthermore, by deconstructing use behaviour into nominal levels, this demonstrates that a simply binary construct is not sufficient. Rather, by attributing qualities to the Levels, such as the standards applied within the UK, the adoption and use behaviour of modular innovations starts to become possible.

Table 7.17 Respondent's perceived business-as-usual BIM Level, by frequency

BIM Level	Freq.	%
Level 0	0	-
Level 0 to 1	0	-
Level 1	4	9.5
Level 1 to 2	17	40.5
Level 2	17	40.5
Level 2 to 3	2	4.8
Level 3	1	2.4

The second measure of Perceived Extent of Use applied a five-point Likert scale to the measurement of the respondent's level of perceived confidence. The results highlight that 35.7% of respondents believe themselves to be *very confident*, 54.8% of respondents believe they are *quite confident* and the remaining 9.5% believe they are in between. No one indicated they felt a lack of confidence in their overall BIM competency.

The last measure seeks to produce a summated score of the respondent's perceived competency in each of the indicated standards. Table 7.18 demonstrates a mixed perception of competency across the BIM Level 2 suite of standards.

Table 7.18 Perceived competency by standard (PU03)

Factor	Mean	SD	Skewness	Kurtosis
BS1192+A2	8.05	2.946	-1.395	0.515
PAS 1192-2	7.81	3.202	-1.466	0.808
PAS 1192-3	6.50	3.263	-0.613	-0.826
BS 1192-4	6.40	3.108	-0.383	-1.016
PAS 1192-5	6.43	3.179	-0.423	-1.126
PAS 1192-6	5.52	3.337	-0.041	-1.348
BS 8536-1	5.24	3.260	-0.108	-1.132
BS 8536-2	4.93	3.453	0.078	-1.405
BS 15978	3.93	3.196	0.445	-1.065

* = Dummy standard used for the descriptive analysis.

Moreover, the perceived level of competency decreases in accordance with the maturity of the standards. For example, BS1192+A2 has the highest mean competency (8.05), and notwithstanding the 2016 addendum, is the oldest standard in the suite - see Appendix A for more details on each of the standards. Whilst the dummy standard (BS15978) received the lowest mean score, it was still selected by several participants. This could suggest either disengaged completion or attempting to promote their BIM proficiency, as seen in Table 7.17.

7.6.2 ACTUAL EXTENT OF ASSIMILATION

The Actual Extent of Assimilation is measured using a series of dichotomous variables. To present a descriptive analysis of the binary responses, the data was coded according to the convention set out by Bartholomew et al. (2008); 1 is used to denote a positive, successful response, whereas 0 indicates a negative or failed response. The raw score is calculated to provide context to the sample, as seen in Table 7.19.

Table 7.19 Descriptive statistics of CDE Use

CDE Use	Freq.	% Cases	% Users
I exchange digital information within a CDE.	30	71.4	83.3
I manage digital information within a CDE.	22	52.4	61.1
I receive and review digital information created by others in a CDE.	28	66.7	77.8
I create digital information with embedded or associated attributes in a CDE.	18	42.9	50
I do not use a CDE.	6	14.3	-

The table demonstrates that six respondents claim to not use a CDE. However, as all respondents indicated that their business-as-usual BIM Level is above Level 1, all respondents are expected to regularly use a CDE solution as part of the BS 1192+A2 standard requirements. This could suggest the presence of an assimilation gap, as explored in the literature review. The raw scores will be dealt with as part of the analysis in Chapter EIGHT. Similarly, the raw scores and percentage of respondents are provided for the BIM-relation activities and information formats in Tables 7.20 and 7.21.

Table 7.20 Descriptive statistics of BIM-related activities

	Activity	Freq.	%
ACT1	Organising information using a classification system	32	76.2
ACT2	Resolving issues using clash detection and 3D coordination	33	78.6
ACT3	Participating in discipline model reviews	34	81.0
ACT4	Using visualisation as a design communication tool	37	88.1
ACT5	Validating non-graphical datasets e.g. testing COBie for completeness	18	42.9
ACT6	Generating non-proprietary file formats for exchange purposes	23	54.8
ACT7	Producing BIM objects to a standard	23	54.8
ACT8	Sourcing BIM objects from a library	24	57.1
ACT9	Producing information for use within an AIM	28	66.7
ACT10	Adhering to digital security strategies/protocols	34	81.0

Table 7.21 Descriptive statistics of BIM information formats

	Information Format	Freq.	%
FORM1	Individual 3D digital design or construction models with embedded or linked attributes	39	92.9
FORM2	Federated 3D models	37	88.1
FORM3	COBie datasets	21	50.0
FORM4	IFC files	31	73.8
FORM5	4D time simulated models	16	38.1
FORM6	5D costs for model attributes	8	19.0
FORM7	6D "as-built" model with operational data	12	28.6
FORM8	2D information generated from scratch	30	71.4
FORM9	2D information generated from a 3D model	37	88.1
FORM10	Design analysis outputs	26	61.9
FORM11	Simulations and visualisations	32	76.2

As the measures applied in Table 7.22 used polytomous scales rather than dichotomous scales, the descriptive statistics will take a form similar to when dealing with perceived competency. Therefore, the mean, standard deviation, and normality data is provided. As reported, respondents appear to be most familiar with the BEP (M = 8.57, SD = 2.795) and least familiar with the OIR (M = 6.90, SD = 3.027). However, all documents are relatively clustered together within a 1.67 spread. Also to note is that the data appears nonnormal across its skewness and kurtosis characteristics.

Table 7.22 Perceived competency by document type

Document	Mean	SD	Skewness	Kurtosis
BIM Execution Plan	8.57	2.795	-2.110	3.379
Plain Language Question	7.02	3.360	-0.896	-0.557
Asset Information Requirements	7.29	2.949	-0.941	-0.306
Project Implementation Plan	8.45	2.062	-1.785	3.667
Task Information Delivery Plan	7.52	3.022	-1.266	0.588
Employer Information Requirements	8.36	2.649	-1.746	1.991
Organisation Information Requirements	6.90	3.027	-0.719	-0.544
Standard Methods and Procedures	7.33	3.273	-1.166	0.093
Master Information Delivery Plan	7.69	3.096	-1.269	0.361
CIC BIM Protocol	7.48	3.179	-1.277	0.393

7.7 Descriptive Analysis of Model Constructs

This section will describe how the respondents answered the questionnaire survey questions related to the constructs of the conceptual model.

7.7.1 Foundational Traits

All items within Table 7.23 exhibit a mean above the scale midpoint ($M > 3.00$). This implies that respondents have a generally positive perception of the internal characteristics conceptualised within this study as Foundational Traits. The descriptive statistics for the Foundational Trait factors are described in more detail as follows:

- Participants' responses regarding Attitude Toward BIM were significantly positive ($M = 4.65$, $SD = 0.828$), although the data appears to be negatively skewed and leptokurtic.
- Risk Propensity also received positive responses indicating participants are more likely to engage in risk-taking behaviour ($M = 3.63$, $SD = 1.092$)
- Respondents also tend to agree with the statements provided regarding their Self-Efficacy ($M = 4.02$, $SD = 0.992$). Notably, respondents were less likely to agree as strongly with two of three of the reverse-coded items.

Table 7.23 Descriptive statistics of the Foundational Trait factors

Factor	Mean	SD	Skewness	Kurtosis
Attitude Toward BIM (α = 0.696)				
AT01	4.76	0.692	-4.288	21.728
AT02	4.64	0.850	-2.971	9.393
AT03	4.55	0.942	-2.807	8.393
Risk Propensity				
RP01	3.21	1.048	0.080	-0.256
RP02	3.17	1.057	-0.219	-0.294
RP03	4.00	1.189	-1.187	0.464
RP04	4.14	1.072	-1.295	0.992
Self-Efficacy (α = 0.725)				
SE01	4.07	1.068	-1.156	0.699
SE02r	4.12	1.087	-1.325	1.477
SE03	4.36	0.727	-1.075	1.303
SE04r	3.36	1.246	-0.094	-1.197
SE05	4.21	0.925	-1.423	2.514
SE06r	3.98	0.897	-1.230	2.249

Note: "r" denotes reverse-coded item.

Note: Reliability scores (α) are provided for reflective constructs.

7.7.2 Environmental Influences

As evidenced in Table 7.24, all factors within the Environmental Influences driver exhibit a mean above the scale midpoint ($M > 3.00$), indicating a generally positive attitude toward these external characteristics.

The descriptive statistics for the Environmental Influences factors are described in more detail as follows:

- The perceptions surrounding External Pressures are moderately positive (*M* = 3.84, *SD* = 1.138).
- Respondents indicated an agreeable attitude toward Facilitating Conditions (*M* = 4.11, *SD* =1.089).
- Respondents acting largely positively to the normative beliefs faction of the Subjective Norms construct (*M* = 4.30, *SD* = 1.067). The overall attitude is also largely positive for motivation to comply (*M* = 4.00, *SD* = 1.102). Interestingly, SN02B is

Table 7.24 Descriptive statistics of the Environmental Influence factors

Factor	Mean	SD	Skewness	Kurtosis
External Pressures				
EP01	3.67	1.243	-0.682	-0.474
EP02	4.17	1.010	-1.096	0.169
EP03	3.67	1.162	-0.476	-0.508
Facilitating Conditions				
FC01	4.19	1.042	-1.489	1.718
FC02	4.40	1.037	-2.142	4.416
FC03r	4.02	1.047	-1.119	0.748
FC04	3.83	1.228	-1.160	0.600
Subjective Norms - Normative Beliefs				
SN01A	4.36	0.983	-1.761	2.910
SN02A	4.38	1.011	-1.740	2.541
SN03A	4.17	1.208	-1.469	1.360
Subjective Norms - Motivation to Comply				
SN01B	4.10	0.906	-1.436	2.816
SN02B	3.81	1.234	-0.681	-0.603
SN03B	4.10	1.165	-1.263	0.797
Top Management Support				
TM01	3.55	1.064	-0.513	-0.575
TM02	3.57	1.252	-0.757	-0.382
TM03	3.98	1.137	-0.998	0.004
TM04	3.62	1.229	-0.951	-0.060
TM05	3.79	1.138	-1.121	0.762

Note: "r" denotes reverse-coded item. Reliability scores (α) are provided for reflective constructs.

noticeably lower than its counterparts (M = 3.81) but yet SN02A achieve the highest mean score across all six determinants (M = *4.38*).

- Respondents appear to perceive Top Management Support somewhat positively when compared to all other factors (M = 3.70, SD = 1.164).
- All factors within the Environmental Influences driver exhibit nonnormal characteristics.

7.7.3 Perceived Benefits

All Perceived Benefit items within Table 7.25 exhibit a mean above the scale midpoint ($M > 3.00$). This implies that respondents have a generally positive perception of BIM's capabilities. This is to be expected to some extent as the respondents were all considered to be adopters, indicating that they have transitioned through the innovation decision making process and have decided to use BIM.

Table 7.25 Descriptive statistics: Perceived Benefit factors

Factor	Mean	SD	Skewnesss	Kurtosis
Improved Coordination (α = 0.813)				
IC01	3.83	1.034	-0.762	0.121
IC02	4.26	0.828	-1.075	0.862
IC03	4.29	0.835	-1.650	4.474
IC04	4.24	0.958	-1.557	2.602
Data Accuracy (α = 0.808)				
AC01r	3.45	1.253	-0.394	-0.910
AC02	3.79	0.925	-0.713	0.794
AC03	3.62	0.909	-0.372	0.440
AC04	4.02	0.897	-0.687	-0.145
Data Reliability (α = 0.701)				
RE01	3.83	1.034	-0.762	0.121
RE02r	4.29	0.835	-1.650	4.474
RE03	4.26	0.828	-1.075	0.862
RE04r	4.24	0.958	-1.557	2.602
Client Satisfaction (α = 0.779)				
CS01	4.19	0.773	-1.015	1.406
CS02	4.07	0.894	-0.574	-0.558
CS03	4.10	0.983	-0.684	-0.708
Task Productivity (α = 0.849)				
TP01	3.86	1.117	-0.808	0.190
TP02	3.83	1.034	-1.040	1.109
TP03r	4.17	1.010	-1.245	1.253

Note: "r" denotes reverse-coded item.

Based on these descriptive statistics, the following conclusions can be drawn:

- Respondents generally reacted positively to the assertion that BIM improves co-ordination (M = 4.16, SD = 0.914), although there is less consensus surrounding agreement on its ability to help practitioners to adjust to changing conditions within project teams, than compared to other IC-related qualities.
- Respondents generally agreed with the statements surrounding Data Accuracy (M = 3.72, SD = 0.996), although to a slightly lesser extent than other Perceived Outcomes.

Notably, the reverse-coded item has a lower mean and higher standard deviation than the other items. However, this is not the case for the other reverse-coded determinants.

- Overall, respondents reacted less favourably to assertions regarding improved Data Reliability, but still exerted a positive perception overall (*M* = 3.48, *SD* = 1.021).
- Respondents generally perceive BIM to improve client satisfaction through meeting client needs and improving overall service to the client (*M* = 4.12, *SD* = 0.883).
- Respondents believe BIM to improve task productivity (*M* = 3.95, *SD* = 1.054).
- With the exception of Data Accuracy, all factors exhibit skewness and kurtosis.

7.7.4 Behaviour Intent

The Behavioural Intent to Continue Use was measured with three items. All items employed a five-point Likert scale ranging from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). Furthermore, as the statements are extremely similar because of their reflective nature, the items were randomly dispersed among questions aiming to elicit information regarding perceived Data Accuracy (PO-AC) and Data Reliability (PO-RE) of BIM to prevent respondent fatigue. The descriptive statistics for each item is provided in Table 7.26.

Table 7.26 Descriptive statistics: Behavioural Intent factor

Factor	Mean	SD	Skewnesss	Kurtosis
Behavioural Intention to Continue Use (*α = 0.818*)				
BI01	4.67	0.754	-3.287	13.371
BI02r	4.57	0.831	-2.517	7.615
BI03	4.67	0.650	-2.340	6.317

Note: "r" denotes reverse-coded item.

The scale used to measure Behavioural Intent to Continue Use, as adopted from Venkatesh (2003) and Wixom and Todd (2005), has been shown to be a true reflective construct (Petter, Straub, and Rai, 2007). Therefore, items BI01, BI02r, and BI03 should be internally consistent and interchangeable (Jarvis, MacKenzie, and Podsakoff, 2003). Table 7.26 confirms internal consistency of the construct with each construct demonstrating a high mean with only a minor discrepancy in the item that employed reverse coding. The consistently high mean (M = 4.63, SD = 0.641) across all three items implies respondents have a strong positive intent to continue using BIM.

7.8 Data Analysis Strategy

A common limitation of many multivariate analytical methods resides in their ability to only consider a single relationship at any one time (Hair et al., 2014a). This can provide constraints on studies which are constructed around a set of interrelated research questions with multiple theorised relationships between constructs. Such complex theoretical models would instead have to be tested in fragments which is generally undesirable (Lowry and Gaskin, 2014). Structural Equation Modelling (SEM) has subsequently emerged as an extension to and an amalgamation of several multivariate methods, most notably Multiple Regression Analysis and Factor Analysis. By utilising the power of a family of statistical models, SEM represents a comprehensive technique for simultaneously testing multiple dependence relationships within the confines of a single theory, thereby overcoming the limitations posed by traditional multivariate techniques.

7.8.1 Structural Equation Modelling (SEM)

SEM is featured as the data analysis method in many survey-based BIM adoption studies, such as in the work of Cao et al. (2014b), Son et al. (2015), Howard et al. (2017), Song et al. (2017), and Wang and Song (2017). Details of these studies and the methods applied are provided in Appendix B. As described by Hair et al. (2014a), structural equation models can be distinguished by three distinct characteristics:

- The ability to estimate multiple and interrelated dependence relationships
- The ability to represent unobserved concepts in these relationships and account for measurement error in the estimation process
- The ability to define a model that explains the entire set of relationships.

To demonstrate these qualities, a basic framework based on a typical structural equation model is illustrated in Figure 7.8. As shown, there are two core elements to SEM: the outer measurement models and the inner structural model.

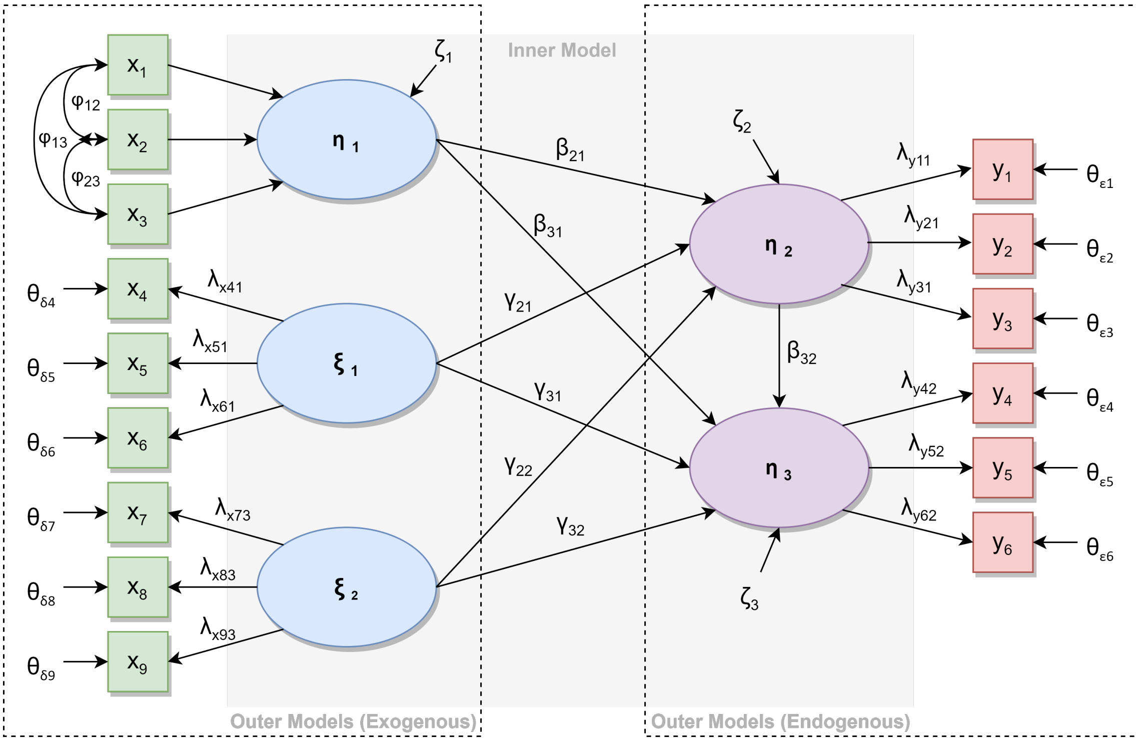


Figure 7.8 Basic framework and notation for Structural Equation Modelling (SEM), adapted from Hair et al. (2014b) to include one exogenous formative factor (η_1).

7.8.2 SEM: Covariance-Based or Partial Least Squares?

There are two distinguishable SEM methods: (1) covariance-based SEM or CB-SEM, and (2) variance-based SEM, known more commonly as partial least squares SEM or PLS-SEM. Whilst Lowry and Gaskin (2014) highlight that many of the characteristics and advantages are shared between the two analysis techniques, Reinartz, Haenlein and Henseler state that both are "essentially two different approaches to the same problem [in that they] both start from the same set of theoretical and measurement equations but differ in how they approach the parameter estimation problem" (2009, p.332). The core difference between the two therefore lies in how latent constructs are estimated: CB-SEM determines how well a model can fit a covariance matrix, whilst PLS-SEM assumes an iterative approach to parameter estimation to maximise the explained variance for all endogenous constructs (Reinartz, Haenlein, and Henseler, 2009).

CB-SEM, as the earlier interpretation of the SEM technique, is traditionally the default method for testing structural equation models. For this reason, analyses are usually conducted using CB-SEM in studies where SEM is specified without explicit reference to the underlying algorithm. However, considerable attention has shifted towards PLS-SEM in recent years across a variety of social science research fields, including marketing, management, business studies (Hair et al., 2014b), and, most notably, within IS settings (Hair et al., 2017a). The acceleration in the use of PLS-SEM as a viable methodology over CB-SEM is typically affiliated with the numerous posited advantages it poses, to the extent of being dubbed a "silver bullet" in causal model estimation by Hair, Ringle, and Sarstedt (2011). Hair et al. (2014b) substantiate this claim through an assessment of previous review studies, finding that the application of PLS-SEM is typically justified over CB-SEM for the following reasons: (1) it can deal with non-normal data distributions, (2) it can achieve higher levels of statistical power with smaller sample sizes than CB-SEM, and (3) it can model formatively measured constructs, which describe latent constructs which are caused by its observable indictors instead of reflectively measured constructs which are typically used.

Although at a glance PLS-SEM can apply to a series of unique situations which prevail those offered by the CB-SEM, a fallacy is arising in which PLS-SEM is being misapplied under the guise of being presented as a superior method. Rather, neither CB-SEM and PLS-SEM is a panacea to solve all problems, with the strengths and limitations of each acting as complimentary reciprocals in one another (Hair et al., 2017; Hair, Ringle and Sarstedt, 2011). This is encapsulated in the discussion and recommendations of Lowry and Gaskin (2014) who highlight that the two methods are equally as advantageous, but through the application of two distinct statistical methods to achieve two different goals. The authors advocate the use of PLS-SEM in instances of preliminary theory building, whereas CB-SEM is generally more suited to model validation. For this reason, Hair et al. (2012) caution against relying on what has recently become a standard set of reasons for using a PLS-SEM approach and instead advise a careful appraisal of the present study. Misapplication or mishandling of the analysis technique can compromise the interpretation of data and undermine the value of the results through erroneous assumptions.

Therefore, to prevent further contribution to the widening fallacy surrounding the erroneous application of PLS-SEM, the decision to apply either a CB-SEM or PLS-SEM technique relies on an appraisal of the techniques in accordance with established guidelines. To do so, a comparison of the CB-SEM and PLS-SEM methods is presented in Table 7.27.

Table 7.27 Comparison between CB- and PLS-Structural Equation Modelling methods, adapted from Hair et al. (2011; 2017a; 2019), Lowry and Gaskin (2014), Sarstedt et al. (2014), Henseler et al. (2016), and Benitez et al. (2020).

Rule of Thumb	CB-SEM	PLS-SEM	Comments
Measurement Model	Reflective factors only.	Reflective and formative factors.	Both reflective and formative constructs are used in this study.
Structural Model	Model is nonrecursive and is simple ($\leqslant$ 5 constructs).	Model is recursive and/or complex ($\geqslant$ 6 constructs) and/or higher order constructs are used.	The model is recursive and has 14 constructs, including one 2nd-order factor.
Normality/ Distribution	Normal distribution only.	No assumptions, but very robust in dealing with nonnormal data.	Several factors exhibit nonnormal distributions based on their skewness and kurtosis values.
Sample Size	Large (>200 is recommended). Small samples will likely not converge.	Large or small (particularly for $n > 30$ and < 100) although small sample sizes will still have a negative impact on results.	The sample size for the present study is < 100.
Model Evaluation	Large	Small or Large	The sample size for the present study is small.
Research Objectives	Confirmation, further testing of theory, and comparison of alternative theories.	Predicting key target factors, identifying key drivers, or for exploratory research. Also can be used for testing extensions to existing structural theory or when using secondary data. Additions to the PLS-SEM method also can make it suitable for causal/explanatory research.	The present study is exploratory. However, CB-SEM could also be used on the basis of theory testing and confirmation.

Following Table 7.27, the PLS-SEM method is the preferred approach for the present study. This is because the study does not meet many of the requirements stipulated by CB-SEM and would instead suit the relaxed assumptions supported by PLS-SEM, such as those surrounding distribution and sample size. Moreover, CB-SEM is limited in dealing with complex models which extend beyond first-order, reflective constructs, which is inherently incompatible with the proposed research model.

7.9 Concluding Remarks

This chapter has discussed the practical implications of the research design for Phase II of the study. It set out the procedures for data collection and analysis, in addition to providing an overview of the demographic profiles of the individual respondents and the organisations they work for. The chapter also presented the descriptive analysis of the constructs and outlined how the data was prepared for the Partial Least Squares Structural Equation Modelling (PLS-SEM) analysis to be conducted in the next chapter.

Chapter Eight

Phase II: A PLS-SEM Analysis

This chapter presents the outcomes of testing the hypotheses using the Partial Least Squares Structural Equation Modelling (PLS-SEM) analysis technique, as discussed in the preceding chapters. In response to the achieved sample size, the chapter first deals with an Exploratory Factor Analysis (EFA) to reduce the factor structure of the reflective constructs. The chapter then seeks to reduce the dimensionality associated with the Actual Extent of Assimilation (AEA) construct by understanding the implications of analysing binary data (i.e. the determinants use dichotomous scales). To do so, an Item Response Theory (IRT) approach is used to compute AEA as a latent trait for input into a PLS-SEM setting. Using a revised BIM Adoption, Assimilation and Use Model (BAAUM), the chapter then deals with the PLS-SEM analysis using the extensive guidance and "rules of thumb" of Hair et al. (2011; 2017a; 2019) and Henseler et al. (2016). The chapter concludes with a summary of the hypothesis testing and a discussion on the implication of the results.

8.1 Exploratory Factor Analysis

To prepare the dataset for PLS-SEM, a Factor Analysis was used to summarise and reduce the factor structure; that is, extracting and defining the underlying grouping of factors based on the strong correlations of determinants. Factor Analyses can be approached from either an Exploratory (EFA) or Confirmatory (CFA) perspective (Hair et al., 2014a). As the name suggests, the former is a heuristic statistical approach which can respond to research objectives without the constraints of a priori assumptions. Conversely, CFAs seek to assess and confirm the degree to which the data fits the theorised structure, either following the factor structure resulting from an EFA or through strong theoretical support in prior research.

Despite efforts to develop determinants from existing measures for use within the questionnaire survey instrument, factors and their determinants were derived from numerous established theories and previous BIM-adoption literature. Therefore, to ensure the determinants included within the instrument were measuring the theorised factors correctly, an EFA was necessary. Moreover, the output of an EFA summarises the determinants into smaller, distinct groups based on factors, which in turn can then be further reduced to achieve a parsimonious set of factors (Hair et al., 2014a).

Given the relatively small size of the sample collected, conducting an EFA was therefore crucial in ensuring the model could be analysed using PLS-SEM. As discussed in Section 7.8, whilst the PLS-SEM algorithm can handle smaller datasets than in CB-SEM, sample size will still affect statistical power particularly when considered in conjunction with higher degrees of model complexity. However, the sample size is also a consideration in conducting a robust EFA with large sizes being generally preferred and the lowest absolute value to be N=50 (Winter, Dodou, and Wieringa, 2009; Hair et al., 2014a). However, de Winter et al. (2009) have challenged this widely accepted understanding by highlighting that well-conditioned data can indeed produce reliable results when N<50. The authors demonstrate that high factor loadings, a low number of factors, and a high number of determinants can produce sufficient results which were robust against small distortions.

8.1.1 Appropriateness and Adequacy of Data

A critical assumption of EFA is that it is only appropriate for sets of determinants which belong to reflective latent factors (Gaskin, 2016). This is because determinants are required to be correlated and interchangeable in order to achieve a meaningful EFA. Therefore, the correlation matrix concerning the relevant determinants listed in Table 8.1 was produced to assess the factorability of the dataset. This matrix maps the correlation between the determinants which, in turn, provides the input to an *R*-type factor analysis. The alternative approach is to derive a *Q*-type correlation matrix which identifies the correlations between individual cases and allows factors to be constructed around similar sets of individuals. However, as the primary objective of the EFA is dimensionality reduction to respond to the small sample size, the latter is not suited to the present study.

Table 8.1 Reflective factors eligible for EFA

Factor	Code	*N* Items
Top Management Support	EC-TM	5
Attitude Toward BIM	FT-AT	3
Self-Efficacy	FT-SE	6
Client Satisfaction	PB-CS	3
Improved Coordination	PB-IC	4
Task Productivity	PB-TP	3
Data Accuracy	PB-AC	4
Data Reliability	PB-RE	4
Behavioural Intention to Continue Use	BI	3
Total:	9	35

As the factors were constructed using *a priori* multi-item indicators to represent the underlying latent constructs, we would expect several correlations to exist between the determinants. Visual inspection of the data matrix confirmed these expectations and identified a substantial number of correlations greater than 0.30 which indicated that factor analysis would be appropriate for the dataset (Hair et al., 2014a). Furthermore, the Bartlett Test of Sphericity produced a significant result (Sig <0.05) which rejects the hypothesis that the matrix is an identity matrix; meaningful correlations can indeed be drawn among at least some of the determinants and therefore further substantiates the suitability for factor analysis. However, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy (MSA) was .468, which is less than the absolute minimum threshold of .50 and the general recommendations of >.60 (Kaiser, 1974). Therefore, remedial action was required to increase the KMO.

To do so, Hair et al. (2014a) suggests analysing the MSA of individual determinants to identify potential candidates for deletion which would in turn increase the overall KMO. This was conducted iteratively by identifying the determinant which has the lowest MSA value from the diagonal of the anti-image correlation matrix and re-running the factor analysis without the identified determinant. This was repeated until all variables had an MSA greater than 0.500.

Table 8.2 Kaiser-Meyer-Olkin sampling adequacy remediation

Iteration	Removed Item	MSA	KMO
1	TM02	.231	.539
2	TM03	.265	.581
3	SE02r	.446	.620
4	SE06r	.377	.627
5	AT03	.407	.628
6	TM01	.350	.634
7	TM05	.457	.676
8	TM04	.385	.697

As demonstrated by Table 8.2, eight determinants were removed following the iterative process, leaving 27 reflective determinants. The Top Management Support factor was also removed after all EI-TM determinants scored less than the satisfactory 0.500 MSA. This means eight factors remain. Moreover, this also means the Environmental Influences driver is not represented within the Exploratory Factor Analysis, as its other factors are formative in nature. Two Self-Efficacy determinants and one Attitude Toward BIM determinant were also removed. The resulting KMO is .697 with a significant Bartlett Test of Sphericity, thus demonstrating an appropriate degree of intercorrelations among the variables for a meaningful EFA to be conducted.

8.1.2 Factor Rotation

The act of rotation enables the resultant pattern of loadings from the PCA to be more pronounced and easier to interpret, with the goal being to achieve a simple structure (Brown, 2009). Hair et al. (2014a) highlights that there are no guidelines for which rotation method to use, with most applications being constrained to the availability of techniques within statistic-based software. However, there are two rotation methods which are distinguished by the assumptions regarding factor correlation: orthogonal methods, which do not allow inter-correlations to exist, and oblique rotation methods which do. For this reason, oblique methods are generally more realistic, particularly when considering applications within the social sciences, as it is unlikely that the underlying dimensions would be entirely independent and uncorrelated. Furthermore, oblique rotation methods are more flexible as the reference axes which are being rotated are not constrained to orthogonal angles, thereby being able to represent the clustering of determinants more accurately (Hair et al., 2014a).

Following the recommendations of Tabachnick and Fiddell (2019), as discussed by Brown (2009), an oblique rotation was trialled to assess the factor correlation matrix for correlations which exceed .32. Correlations meeting this criterion indicates there is enough overlap in variance among factors to warrant oblique rotation. Using the Promax technique offered in the SPSS v16.0 package, the reproduced correlation matrix was visually inspected and sufficiently met the requirements for oblique rotation. Moreover, when the resultant pattern matrix was assessed against the rotated components matrix produced using the orthogonal Varimax technique, the Promax rotation produced a cleaner structure which strongly supports the use of oblique rotation for the present study (Brown, 2009).

8.1.3 Factor Interpretation

The rotated factor pattern matrix was visually inspected to identify significant loadings. Following Hair (2014a), factor loadings below 0.75 were dropped to maintain statistical significance at the .05 level with a power level of 80%. Loadings which fell below the absolute value of .55 threshold were suppressed, allowing cross-loadings which fell with a .2 range to be identified. As a rule of thumb, it is generally advisable to have loadings which are greater than 0.5 which average out to greater than 0.7 per factor (Gaskin, 2016). Several determinants suffered problematic cross-loadings and were iteratively removed from each rotation.

This resulted in 16 determinants loading onto three factors, as presented in Table 8.3. Considering the small sample size, determinants with factor loadings <.75 were retained on the advice of de Winter et al. (2009). The authors recommend increasing the number of variables, where possible without undermining quality, when dealing with small sample sizes. Moreover, as the convergent validity of each resultant factor averaged >0.75, the factor structure was considered suitable.

Table 8.3 Exploratory Factor Analysis factor loadings

Factor	One	Two	Three
RE01	**0.913**	-0.124	-0.107
AC03	**0.895**	-0.154	0.054
AC02	**0.844**	-0.067	0.078
RE03	**0.763**	0.282	-0.057
IC03	**0.735**	0.044	0.016
AC01r	**0.655**	-0.109	0.146
AC04	**0.631**	0.412	-0.169
BI01	-0.030	**0.926**	0.055
AT01	-0.011	**0.892**	-0.137
BI03	0.025	**0.857**	0.161
AT02	-0.116	**0.834**	0.020
TP03r	-0.198	0.076	**0.953**
TP02	-0.081	0.101	**0.912**
TP01	0.048	-0.100	**0.756**
CS02	0.241	-0.103	**0.709**
CS03	0.302	0.074	**0.617**

Bold values represent the factor loadings of the items on their respective constructs.

Table 8.4 (see next page) presents the emergent factors and how each item has been grouped and recoded. The first grouping contains variables from within the Perceived Benefits construct, namely factors relating to Data Accuracy (PB-AC), Data Reliability (PB-RE), and a single Improved Coordination (PB-IC) determinant. Beyond the commonality of the PB driver, each determinant is in some way related to Data Quality and is therefore labelled as such.

The second grouping concerns factors relating to Attitude Toward BIM (FT-AT) and Behavioural Intention to Continue Use. Whilst not theorised to share a relationship, each pertain to the degree of favourability relating to the continuance of BIM use. Therefore, Attitude Toward BIM and Behavioural Intention to Continue Use are grouped and recoded as Attitudinal Intent (AI).

The third and final grouping also relates to factors within the Perceived Benefits driver. Three determinants relating to Task Productivity (PB-TP) and two relating to Client Satisfaction (PB-CS) were found to load together. As these factors relate to the satisfactory delivery of information, this last factor is labelled as Delivery Performance (PB-DP).

Table 8.4 Emergent EFA factors and their determinants

Orig.	Recoded	Determinant
Attitudinal Intent (AI)		
BI01	**AI01**	I plan to continue using BIM.
AT01	**AI02**	Using the system is a bad/good idea.
BI03	**AI03**	I predict I would continue using BIM.
AT02	**AI04**	I dislike/like the idea of using the system.
Delivery Performance (PB-DP)		
TP03r	**DP01r**	Using BIM decreases my productivity.
TP02	**DP02**	Using BIM saves my time.
TP01	**DP03**	Using BIM allows me to accomplish more work than would otherwise be possible.
CS02	**DP04**	Using BIM improves client satisfaction.
CS03	**DP05**	Using BIM improves service to the client.
Data Quality (PB-DQ)		
RE01	**DQ01**	The data that BIM provides is exactly what I need to carry out my tasks.
AC03	**DQ02**	The data I receive from BIM tools and processes is true.
AC02	**DQ03**	The information that BIM tools and processes provides to me is accurate.
RE03	**DQ04**	The data accessible from BIM applications and processes lacks critical information that would be useful to me.
IC03	**DQ05**	Using BIM makes me aware of important information from other project team members.
AC01r	**DQ06r**	The information from BIM applications and processes has numerous accuracy problems that make it difficult for me to do my job.
AC04	**DQ07**	BIM data that I use or would like to use are accurate enough for my purposes.

Note: "r" denotes reverse-coded item.

8.1.4 Emergent Factor Validity and Reliability

The descriptive statistics for the emergent constructs are presented in Table 8.5. As demonstrated within the table, the Cronbach's Alpha (α) was computed for each transformed factor and was found to satisfy the $\geqslant$0.7 criterion for reliability. The table also presents the extraction sums of the square loadings, which states that the three factors cumulatively explain 70.9% of the total variance in the items.

Table 8.5 Emergent factor validity and reliability

Factor	α	**Correlation**			**Extraction Sums of Square Loadings**		
		AI	**PB-DP**	**PB-DQ**	**Total**	**% Var.**	**Cum.%**
PB-DP	0.879	1.000	0.300	0.396	6.449	40.306	40.306
AI	0.896	0.300	1.000	0.258	2.702	16.889	57.195
PB-DQ	0.879	0.396	0.258	1.000	2.200	13.752	70.948

Based on the pattern matrix presented in Table 8.3, the emergent factors were also assessed for validity based on the guidelines set out by Hair et al. (2011) and Gaskin (2016):

- All groupings make theoretical sense, thereby confirming each factor's face validity.
- All factor loadings presented in Table 8.5 exceed 0.5 and average out to 0.777, 0.877, and 0.789 for the PB-DQ, AI, and PB-DP factors respectively, thereby confirming convergent validity.
- Based on the component correlation matrix presented in Table 8.5, there are no correlations exceeding 0.7 which would otherwise indicate discriminant validity issues.

8.1.5 Revised Model and Hypotheses

The Foundational Traits driver has reduced from three factors to considering the formative construct of Risk Propensity only. Despite the evidence supporting the theoretical relationships presented in Chapter SIX, the revised model drops the drivers and presents the

Antecedent Drivers as distinct factors. The revised hypotheses are therefore provided as follows:

Hypothesis 1a. *The individual's risk propensity in construction projects is positively associated with their perceived extent of use.*

Hypothesis 1b. *The individual's risk propensity in construction projects is positively associated with their actual extent of assimilation.*

Hypothesis 2a. *There is a positive relationship between external pressures and an individual's perceived extent of use of BIM.*

Hypothesis 2b. *There is a positive relationship between external pressures and an individual's actual extent of assimilation of BIM.*

Hypothesis 3a. *Facilitating conditions have a positive influence on an individual's perceived extent of use of BIM.*

Hypothesis 3b. *Facilitating conditions have a positive influence on an individual's actual extent of assimilation of BIM.*

Hypothesis 4a. *The subjective norms are positively related to an individual's perceived extent of use.*

Hypothesis 4b. *The subjective norms are positively related to an individual's actual extent of assimilation.*

Hypothesis 5. *An individual's perceived extent of use of BIM has a direct relationship with their actual extent of assimilation.*

Hypothesis 6a. *There is a direct relationship between perceived extent of use and perceived benefits.*

Hypothesis 6b. *There is a direct relationship between perceived extent of use and attitudinal intent to continue use*

Hypothesis 7a. *There is a direct relationship between actual extent of assimilation and perceived benefits.*

Hypothesis 7b. *There is a direct relationship between actual extent of assimilation and attitudinal intent to continue use.*

Hypothesis 8. *The perceived benefits have a positive influence on the individual's attitudinal intent to continue use.*

As a second-order factor within the focal relationship of the BAAUM, the hypotheses concerning the Perceived Benefits driver remain. However, the revised internal structure is presented in Figure 8.1, in which the revised first-order factors are modelled as reflective and the second-order factor is modelled as formative. The full revised model and its hypotheses are presented in Figure 8.2 (see next page).

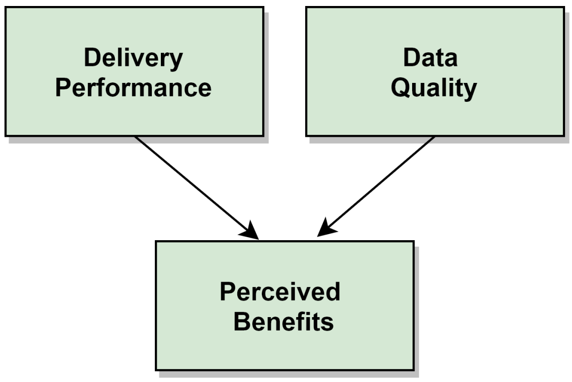


Figure 8.1 Revised Perceived Benefits 2nd-order factor structure

8.2 DICHOTOMOUS MEASUREMENT MODEL

Many scholars note the ability of PLS-SEM to process variables which are measured using a combination of nominal, ordinal, interval, and ratio scales (e.g. Reinartz, Haenlein, and Henseler, 2009; Hair et al., 2012a; Hair et al., 2012b). Yet, PLS-SEM literature tends to focus on the implications of applying nominal and binary variables either in an exogenous setting (e.g. Bodoff and Ho, 2016) or as a dummy variable within a controlling or moderating capacity (e.g. Henseler, Hubona, and Ray, 2016). However, such categorical constructs can also play an active role in model construction (Trinchera, Russolillo, and

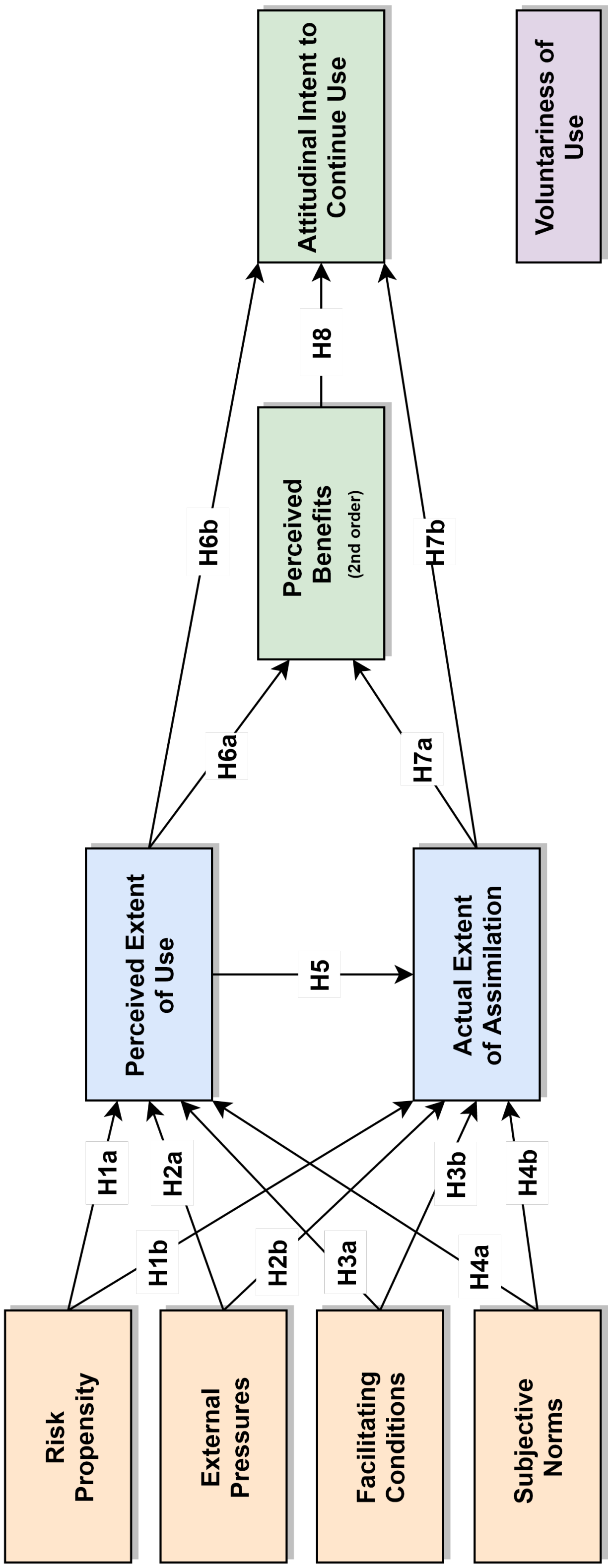


Figure 8.2 Revised BIM Adoption, Assimilation and Use Model (BAAUM) using the EFA emergent factors

Lauro, 2008). Nevertheless, Bodoff and Ho (2016) highlight the lack of knowledge base surrounding how to use binary data in an endogenous setting.

To evaluate the dichotomous measurement model, factor analysis was considered for the Actual Extent of Assimilation (AEA) construct. However, traditional factor analytic methods, such as the EFA conducted in the previous section, are better suited to continuous or ordinal data, rather than dichotomous or even polytomous items (Woods, 2002). Rather, this study looks towards test theory from which to derive a score to represent AEA within a PLS-SEM setting. Fundamentally, test theory concerns itself with how to infer estimates of a latent trait based on a series of categorical manifest determinants. As such, test theory can be used as a measurement model within a SEM context (Bulut, Quo, and Gierl, 2017).

8.2.1 Test Theory Approach

There are two schools of thought relating to test theory: Classical Test Theory (CTT) and Item Response Theory (IRT). In CTT, emphasis is placed on total summated test scores, as explained here:

$$X = T + E \tag{8.1}$$

CTT assumes that observed score X is the sum of the individual's true score T and a degree of random measurement error E. This approach has formed the dominant approach to measurement scales in empirical IS research (Rusch et al., 2017). However, the assumptions held by CTT have implications when applied to categorical measures, particularly in relation to the validity and reliability of results (Bortolotti et al., 2013; Rusch et al., 2017). Notably, CTT assumes a linear relationship between the observed scores and the latent variable and therefore naturally lends itself to metric analysis methods developed for discrete, interval scales (Bartholomew et al., 2008; Boone, 2016; Rusch et al., 2017).

On the other hand, IRT, otherwise known as latent trait theory, offers an item-centric approach to measurement (Bortolotti et al., 2013; Rusch et al., 2017). IRT estimates properties of the items from the data, such as its difficulty, and uses these estimates to show the relationship between a latent trait and the item responses (DeMars, 2010). Notably, an IRT analysis estimates trait scores for individuals based on calibrated, weighted items

(Toland, Bowen, and Dueber, 2020). Consequently, IRT has been used in multiple fields which require a quantitative scale for measuring an individual's proficiency or ability, such as educational measurement, psychology, sociology, political science, and medical research (Sjitsma, 2004).

Although there were no previous studies which apply an IRT approach to BIM assimilation or competency, IRT has been employed recently in other related areas. For example, in a construction-specific context, Zhou and Guo (2020) used IRT to measure and rate the safety response competency of labourers (*N* = 43) on subway construction projects in China. Toland et al. (2020) use IRT to examine the psychometric properties of the occupational health and well-being assessment of construction professionals (*N* = 864) in South Africa. Resende et al. (2020) applied an IRT model to construct a psychometric profile of Brazilian construction professionals (*N* = 95) in an attempt to better understand their environmental competency sets.

There are multiple IRT models built around the different assumptions regarding the relation between the level of the latent trait and the answer choices (Bortolotti et al., 2013). This study looks to adopt a cumulative IRT model, which posits that the probability of an individual selecting a positive response to an item increases as their latent trait increases. Within the context of this study and more specifically at the AEA construct, it is argued that higher levels of actual assimilation leads to a higher probability of positive responses indicating the actual use of the BIM-related element being assessed.

Due to the nature of the collected data, a one-parameter logistic dichotomous model is used: the Rasch model (Rasch, 1960). The Rasch model describes a logistic relationship between a person's latent ability and the probability of a "correct" response on an item. The Rasch model is expressed as:

$$Px_j = 1|\theta, b_j = e\theta, -b_j 1 + e\theta, -b_j \tag{8.2}$$

where x_j is the response to item j, P is the probability of a positive selection, or in traditional IRT terms, a 'correct' response, θ is the latent trait, and b_j is the difficulty of the item[1]. As with other statistical analysis techniques, a small sample size can have implications on the robustness of estimates and fit analyses. However, for exploratory research, Linacre (1994) states that Rasch analysis can produce statistically stable measures ($\pm$1.0 logits, 95% confidence) with 30 participants. Therefore, the sample size achieved in this study is suitable for a Rasch analysis.

Therefore, IRT within this research serves a triad of functions: (1) to evaluate the dichotomous measurement model with a technique analogous to the factor analysis approaches used for the other constructs, (2) to achieve dimensionality reduction for model parsimony within a PLS-SEM environment, and (3) to attempt to capture the extent of an individual's assimilation as a latent trait through a test theory lens. The Rasch analysis was conducted using the Extended Rasch Modelling package in R and the R Plug-In for SPSS (Mair and Hatzinger, 2007; Mair, Hatzinger, and Maier, 2020).

8.2.2 ASSESSING MODEL FIT

The suitability of the data for Rasch analysis relies on it ability to fit within the model (Boone and Noltemeyer, 2017). Two types of mean-square fit statistics - the infit and outfit t-statistics - were assessed. The former is an information-weighted, inlier-sensitive fit, whilst the latter is an unweighted fit which is sensitive to outliers (Linacre, 2002). These statistics are commonly reported as the mean of the squared residuals for an item or person (Msq) and as the z-standardised transformation of the mean-square using a sample size correction (Zst).

Msq statistics assess the extent of distortion and randomness with an expected value of 1.0 (Linacre, 2002). Reasonable Msq ranges for infit and outfit based on the type of test being implemented have been outlined by Bond and Fox (2013). The scholars state that for 'run of the mill' multiple choice questions, the Msq values should fall between 0.7 and 1.3. However, Linacre (2002) presents a case for considering between 0.5 and 1.5 as "productive for measurement", whilst also acknowledging that lower values, such as those below 0.5, do not harm results in a Rasch context but are instead considered less productive.

[1] The nomenclature used here differs from other publications, which tend to use β to represent item difficulty. However, b is used to prevent confusion with the notation used for path coefficients (see Figure 7.8).

However, values exceeding 2.0 result in an inaccurate or distorted measurement system. Therefore, items with infit or outfit values that exceed 2.0 should be reviewed and carefully evaluated.

Zst statistics, which are expressed as *z*-scores, assess the predictability and significance of the data. As the expected value is 0.0, negative values indicate increased predictability, whereas positive values indicate a lack of predictability (Linacre, 2002). As a *t*-test value, the Zst should conventionally be within ± 1.96 at the 95% confidence level. Within a Rasch modelling context, Linacre (2002) asserts that data exceeding 2.0 is "noticeably unpredictable" whilst values exceeding 3.0 are considered a substantive misfit. On the inverse, data achieving less than -2.0 is considered "too predictable" and could constrain response patterns. Therefore, items that fall outside the ± 2.0 range should be flagged and assessed accordingly.

The item statistics are presented in Table 8.6 (see next page). As highlighted, FORM8 exceeds the 2.0 threshold for its outfit Msq value (2.40), whereas all other values fulfil the criterion (<1.5). Furthermore, its infit and outfit Zst values also exceed the maximum thresholds (2.12 and 3.25 respectively), signifying that its predictability is unfavourable and may not fit the model. As such, FORM8 will be closely monitored for further issues as the analysis progresses.

Table 8.6 Item fit statistics

Item	*T*	*b*	SE	Infit		Outfit		PTMC
				Msq	Zst	Msq	Zst	
FORM6	8	2.62	0.43	0.90	-0.35	1.06	0.28	0.44
FORM7	12	1.97	0.38	1.18	0.96	1.35	1.16	0.27
FORM5	16	1.43	0.36	0.96	-0.21	1.04	0.27	0.47
ACT5	18	1.18	0.35	0.95	-0.29	1.00	0.05	0.49
CDE4	18	1.18	0.35	0.75	-1.77	0.66	-1.87	0.67
FORM3	21	0.81	0.35	1.05	0.39	1.09	0.52	0.41
CDE2	22	0.69	0.35	0.82	-1.35	0.76	-1.31	0.60
ACT6	23	0.58	0.35	0.79	-1.67	0.70	-1.61	0.63
ACT7	23	0.58	0.35	1.02	0.16	1.16	0.81	0.41
ACT8	24	0.46	0.35	1.28	1.98	1.46	1.99	0.18
FORM10	26	0.21	0.35	1.09	0.72	1.04	0.23	0.36
ACT9	28	-0.04	0.36	1.08	0.59	1.17	0.66	0.32
CDE3	28	-0.04	0.36	1.04	0.30	1.01	0.14	0.38
CDE1	30	-0.31	0.37	0.82	-1.11	0.73	-0.82	0.53
FORM8	30	-0.31	0.37	1.37	**2.12**	**2.40**	**3.25**	**-0.04**
FORM4	31	-0.45	0.38	0.97	-0.13	0.85	-0.33	0.41
ACT1	32	-0.60	0.39	0.82	-0.98	0.62	-1.00	0.53
FORM11	32	-0.60	0.39	1.12	0.66	1.23	0.69	0.25
ACT2	33	-0.75	0.40	0.85	-0.71	0.61	-0.93	0.50
ACT3	34	-0.92	0.42	0.77	-1.00	0.53	-1.06	0.54
ACT10	34	-0.92	0.42	1.19	0.88	1.22	0.59	0.16
ACT4	37	-1.54	0.50	0.95	-0.04	0.69	-0.31	0.33
FORM2	37	-1.54	0.50	0.77	-0.63	0.45	-0.85	0.48
FORM9	37	-1.54	0.50	0.98	0.06	1.39	0.75	0.21
FORM1	39	-2.15	0.62	1.07	0.30	1.37	0.66	0.11
Mean	26.9	.00	0.40	0.98	.00	1.02	0.10	-
σ	8.10	1.14	0.07	0.16	1.00	0.40	1.10	-

Note: SE = Standard Error, *b* = Item Difficulty, PTMC = Point-Measure Correlation, σ = Standard Deviation.

8.2.3 Item Polarity and Remediation

The point-measure correlation coefficient assesses whether the responses to the item align with the direction of the latent trait. Therefore, we expect to see noticeably positive correlations for these items. However, as highlighted in Table 8.6, item FORM8 was identified as achieving a negative point-measure correlation (-0.40), suggesting the item polarity is in reverse to that of the latent trait. Upon further inspection, it is found that the item seeks to capture an individual's interaction with 2D information which is created from scratch. Due to the manual nature of the construct (i.e. aligning with traditional CAD-based work processes, rather than with BIM), it could be viewed as having a reverse scoring effect on the data. As FORM8 was also considered problematic when reviewing the data fit, the item was therefore dropped and the analysis was re-run with the remaining 24 items to assess for further discrepancies.

As shown in Table 8.6, item ACT8 had Zst values of 1.98 (infit) and 1.99 (outfit) prior to the re-run. Following reanalysis, these vlaues became inflated to 2.31 and 2.91 respectively, in addition to achieving 1.91 for the outfit Msq. ACT8 ("sourcing BIM objects from a library") was therefore removed. A further re-run of the analysis showed no further concern[2]. The item fit statistics tables can be found in Appendix F.

8.2.4 Item Parameters and Characterstics

The eRm package for R estimates item parameters using conditional maximum likelihood (CML) estimation (Mair and Hatzinger, 2007). The item parameter represents the "easiness" of the item, or rather, where on the latent trait it lies such that the probability of scoring 1 lessens as its value increases (Rusch et al., 2017). DeMars describes this 'difficulty' parameter *b* as "the amount of the trait that is needed to be more likely to choose the response scored 1 than the response scored 0" (2010, p.7). In other words, item difficulty does not pertain to the amount of effort required as the label suggests, but rather to the point on the latent trait scale at which the probability of endorsing an item is 50%. However, to align with the terminology used by Rasch scholars, the item parameters are discussed in terms of difficulty.

As illustrated in Table 8.7, ACT4 ("using visualisation as a design communication tool") is the easiest item in the set (-1.59 logits) and ACT5 ("validating non-graphical datasets") is the most difficult item (1.19 logits). In terms of BIM assimilation, visualisation is the most conducted activity which is unsurprising given the emphasis on the 3D environment its principles are built on. This finding corroborates that of Cao et al. (2015) who found BIM use to be principally focussed visualisation-related activities, rather than areas relating to

[2] The outfit Msq values for items FORM11, FORM9, and FORM1 exceed 1.5. However, all other values were satisfactory so no further remediation was required (Linacre, 2002)

management, analysis, and simulation. Conversely, the data suggets that the validation of non-graphical datasets, such as COBie, is not done as much by individuals, which aligns with the fact that only a third of organisations exchange information in a COBie format (NBS, 2020).

Table 8.7 Item difficulty parameters: BIM-related activities

	Activity	*T*	*b*	SE
ACT1	Organising information using a classification system	32	-0.62	0.40
ACT2	Resolving issues using clash detection and 3D coordination	33	-0.79	0.41
ACT3	Participating in discipline model reviews	34	-0.96	0.43
ACT4	Using visualisation as a design communication tool	37	-1.60	0.50
ACT5	Validating non-graphical datasets	18	1.23	0.36
ACT6	Generating non-proprietary file formats for exchange purposes	23	0.60	0.36
ACT7	Producing BIM objects to a standard	23	0.60	0.36
ACT9	Producing information for use within an Asset Information Model	28	-0.05	0.37
ACT10	Adhering to suitable strategies/protocols regarding digital security	34	-0.96	0.43
Mean		28.6	-0.28	0.40

Note: *T* = Total Score, *b* = Item Difficulty, SE = Standard Error.

Note: Due to recalculation following the removal of FORM8 and ACT8, the *b* values differ from those in Table 8.6.

Table 8.8 presents the item parameters for the interaction with information within a CDE items. Whereas BIM-related activities and processes can be considered easier (mean = -0.28 logits), interaction with information within a CDE is perceived to be more difficult to endorse (mean = 0.40 logits). Out of the four items, CDE4 ("I create digital information with embedded or associated attributes in a CDE") is perceived to be the most difficult item in the set. This is unsurprising as many CDE solutions do not facilitate an active working environment and instead function more so as a document management system facilitated by CDE workflows and status codes. Therefore, the ability to 'create' information is limited. Furthermore, this item to some degree relies on the other items, in that to create information, it is generally expected that information is also managed and reviewed within the CDE. On the other hand, CDE1 ("I exchange digital information within a CDE") is the easiest CDE-related item, with an item difficulty value of -0.32 logits. This reflects general adherence to the BS 1192 standard which governs the collaborative exchange of information. However, as a core underlying principle of the BIM Levels, it is surprising that 28.6% of respondents do not use a CDE to exchange information. This finding supports the proposition that an assimilation gap effect may be occurring.

Table 8.8 Item difficulty parameters: Interaction with information within a Common Data Environment

Information Interaction		*T*	*b*	**SE**
CDE1	I exchange digital information within a CDE.	30	-0.32	0.38
CDE2	I manage digital information within a CDE.	22	0.72	0.36
CDE3	I receive and review digital information created by others in a CDE.	28	-0.05	0.37
CDE4	I create digital information with embedded or associated attributes in a CDE.	18	1.23	0.36
Mean		24.5	0.40	0.37

Note: *T* = Total Score, *b* = Item Difficulty, SE = Standard Error.

Note: Due to recalculation following the removal of FORM8 and ACT8, the *b* values differ from those in Table 8.6.

Table 8.9 demonstrates that interaction with BIM information formats has a relatively neutral mean item difficulty (0.10 logits). The table also demonstrates a broad range of item difficulties: the easiest item, FORM1, has a value of -2.22 logits and the most difficult item, FORM6, has a value of 2.82 logits. These results are not surprising; FORM1 measures respondent interaction with "Individual 3D digital design or construction models with embedded or linked attributes" which represents the core element of Level 2 BIM in

Table 8.9 Item difficulty parameters: BIM information formats

Information Format		*T*	*b*	**SE**
FORM1	Individual 3D digital design or construction models with embedded or linked attributes	39	-2.22	0.62
FORM2	Federated 3D models	37	-1.60	0.50
FORM3	COBie datasets	21	0.85	0.36
FORM4	IFC files	31	-0.47	0.39
FORM5	4D time simulated models	16	1.50	0.37
FORM6	5D costs for model attributes	8	2.82	0.46
FORM7	6D "as-built" model with operational data	12	2.09	0.40
FORM9	2D information generated from a 3D model	37	-1.60	0.50
FORM10	Design analysis outputs	26	0.22	0.36
FORM11	Simulations and visualisations	32	-0.62	0.42
Mean		28.6	0.10	0.39

Note: *T* = Total Score, *b* = Item Difficulty, SE = Standard Error.

Note: Due to recalculation following the removal of FORM8 and ACT8, the *b* values differ from those in Table 8.6.

accordance with the Bew-Richards maturity wedge. On the other hand, FORM6 concerns user interaction with 5D costs for model attributes, which can be considered a specialist activity in that only cost consultants would be regularly involved in such formats. As expected the next most difficult item is FORM7 which seeks to measure the usages of 6D information. Whilst it is understood that it is unlikely that every member of a project team would need to interact with facilities management information, it is likely that there will be more interaction than with 5D data, particularly considering COBie data inputs and Soft Landings procedures.

All item parameters are presented as item characteristic curves to diagrammatically illustrate the relationship between item difficulty and the probability of endorsement. This item characteristic curve (ICC), or item response function, is a monotonous logistic function which examines the individual's latent ability and its placement on the latent continuum (Kreiner, 2013). An ICC is presented as a line graph which is plotted against the probability of a response on the y-axis and the amount of the latent trait on the x-axis, i.e. the shape of the curve describes the relation of the change in the latent trait with the change in the probability of an endorsement (Bortolotti et al., 2013). This function, as defined within the Rasch model for dichotomous data, can be expressed as follows:

$$P(X_{vi} = 1|\theta_v, b_i) = p_v i = \frac{exp(\theta_v - b_i)}{1 + exp(\theta_v - b_i)} \tag{8.3}$$

In the above formulation, the probability of a positive response P_{vi} to item i by person v is a function of the person's latent ability θ_v and item difficulty b.

The ICC for all items is presented in Figure 8.3. ICC plots for each assimilation area (i.e. BIM-related activities and processes, interaction with information within a CDE, and BIM information formats) are provided in Appendix F. As illustrated within the diagram, the ICCs for Rasch models will never cross due to its unidimensionality, or the absence of item discrimination. Item discrimination, or the a-parameter, would otherwise be found in two- and three-parameter logistic models (DeMars, 2010).

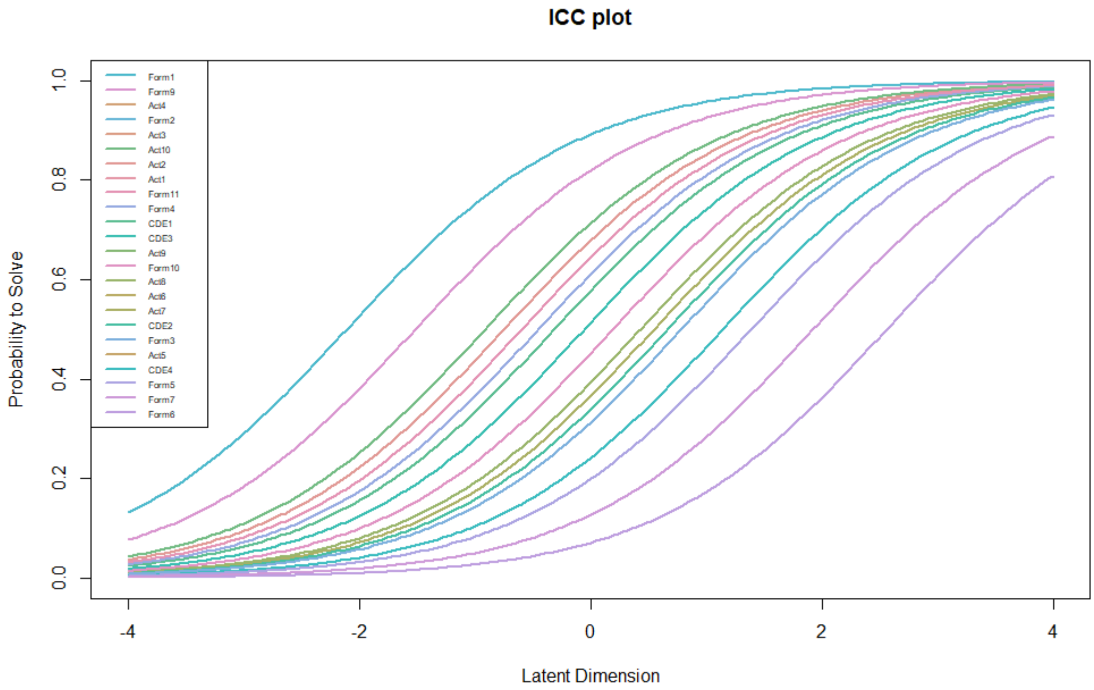


Figure 8.3 Item Characteristic Curve: BIM-related activities and processes

8.2.5 Person Parameters

The person parameter represents the latent ability of the respondent. As with the fallacy associated with item parameter, the term *latent ability* does not necessarily equate to the educational ability or performance of the person, but rather any underlying latent trait. Kreiner (2013) provides the level of depression as measured within health sciences, as an example of a person parameter. One of the key advantages of applying an IRT approach is that item parameters and person parameters are not interdependent (Bortolotti et al., 2013; Rusch et al., 2017). Therefore, the latent traits of individuals across different populations can be compared when administered with the same instrument without compromising the integrity or characteristics of the determinants.

Logically, the person parameter dictates that the higher the latent trait, the better the raw score and therefore performance (Boone, 2016; Boone and Noltemeyer, 2017). As with item parameters, person parameters lie on a metric scale and are measured in units of logits (Boone and Noltemeyer, 2017). However, where item parameters are estimated by conditioning the likelihood on the sufficient person raw score, person parameters are estimated separately by calibrating the item parameters and the person parameters on a shared continuum (Mair and Hatzinger, 2007; Granger, 2008). This can be seen in the person-item map provided in Appendix F, which sets out the distribution of the respondents and the items on a common logit scale.

In this study, estimates of person parameters are presented as measures of assimilation within the subjects. These *a posteriori* person parameter scores and the associated standard errors of estimate were estimated for the collected sample and are reported in Table 8.10.

Table 8.10 Person parameters by score achieved

Raw Score	θ	**SE**	**%**	**Cum. %**
6	-1.41	0.52	2.4	2.4
8	-0.91	0.49	2.4	4.8
9	-0.68	0.48	2.4	7.1
10	-0.46	0.47	9.5	16.7
12	-0.02	0.47	14.3	31.0
13	0.20	0.47	9.5	40.5
14	0.42	0.47	9.5	50.0
15	0.64	0.48	4.8	54.8
16	0.88	0.49	4.8	59.5
17	1.13	0.51	2.4	61.9
18	1.40	0.53	9.5	71.4
19	1.69	0.56	4.8	76.2
20	2.03	0.61	11.9	88.1
21	2.44	0.67	2.4	90.5
22	2.96	0.79	4.8	95.2
23	3.78	1.06	4.8	100.0

Note: θ = Latent Trait, SE = Standard Error.

8.2.6 Implications and Use within PLS-SEM

Thus far, this section has analysed the dichotomous data collected for the Actual Extent of Assimilation construct using the Rasch model. Whilst producing valuable insights for this construct in itself, this method is primarily used within the study as a precursor to a full PLS-SEM approach. It therefore becomes necessary to understand the implications of using the output of a Rasch analysis within a traditional PLS-SEM setting in which the dominant focus is on reflective and formative factors (e.g. Hair et al., 2019).

Christensen et al. (2012) argue that a Rasch analysis does not benefit from additional input from a Factor Analysis and can be integrated into SEM directly. Building on the work of Takane and de Leeuw (1987), Lu et al. (2005) highlight the mathematical connection between IRT and SEM, stating that "the IRT model is automatically embedded in the structural equation model" (2005, p.271). Glockner-Rist and Hoijtink (2003) conclude that IRT methods can enhance SEM by improving factor score estimators, providing methods to explore model fit at the person level, and enabling adaptive testing and item banking. Moreover, Henseler et al. (2016) praise PLS path modelling for its modularity, highlighting that its steps can be replaced by other approaches, using principal components factor analysis as an example. Therefore, following Glockner-Rist and Hoijtink (2003) and Christensen et al. (2012), an integrated IRT-SEM approach for the analysis of dichotomous data is used.

Salzberger (2011) presents a methodology for utilising the Rasch measure as a single item indicator within SEM - see Figure 8.4. Generally speaking, the use single-item measures are discouraged, particularly where multi-item scales can be employed instead (Hair et al., 2019). This is because their presence may lead to poor outer model quality in terms of predictive validity (Hair et al., 2012a; Ringle, Sarstedt, and Straub, 2012).

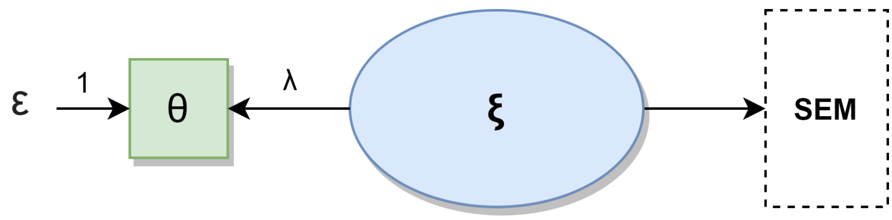


Figure 8.4 The Rasch person measure (θ) as a single-item indicator of a latent variable (ξ), adapted from Salzberger (2011)

However, PLS-SEM is noted for its ability to accommodate single-item measures (Hair et al., 2012a). Yet, a key criticism of using single-item constructs in any SEM setting is the inability to assess the reliability and internal consistency of the construct using traditional methods such as Cronbach's Alpha. The application of the Rasch analysis therefore circumnavigates this issue by calculating score reliability and consistency as part of the procedure which can later be inputted into the PLS-SEM software (Rusch et al., 2017). Therefore, applying a single-item measure derived from a Rasch analysis does not present the same reliability concerns as traditional applications of single-item measures.

According to Salzberger (2011), there are four elements to be considered: the Rasch person measure (θ) which is situated as the determinant within the measurement model setting, an estimate of the error variance (σ_{ε}^2), an estimate of the regression coefficient (λ), and an estimate of the variance of the latent variable (σ_{ξ}^2). The error variance is calculated using the reported estimates of the separation reliability, also known as the Person Separation Index[3] (0.8169) and the standard deviation of the person measure σ_θ (1.311). The calculation is as follows:

$$\sigma_\theta^2 = \sigma_\xi^2 \cdot (1 - PSI) = 1.311^2 \cdot (1 - 0.8169) = 0.3146 \qquad (8.4)$$

With the variance of the latent variable constrained to 1, the regression coefficient λ is calculated as follows:

$$\lambda = \sigma_\theta \cdot \sqrt{PSI} = 1.311 \cdot \sqrt{0.8169} = 1.185 \qquad (8.5)$$

8.3 Reflective Measurement Model

As highlighted during the EFA, reflective measurement models need to be evaluated for factor validity and reliability. The reliability and validity of the emergent reflective constructs were partially addressed in Section 8.1. However, for a complete assessment within the context of their application within a PLS-SEM context, this section follows the guidelines for reflective measurement model evaluation as set out by Wong (2013) and Hair et al. (2011; 2019). These steps are: assessing the internal consistency reliability, indicator reliability, convergent validity, and discriminant validity.

[3] This is the Rasch equivalent of the reliability assessment, as measured using Cronbach's Alpha (α), in Factor Analysis (Salzberger, 2011).

8.3.1 Internal Consistency Reliability

As a condition for validity, internal consistency reliability should be checked first (Wong, 2016). This refers to the assumption that all reflective determinants are equally reliable. To assess internal consistency reliability, the composite reliability, ρ_A, and Cronbach's Alpha (α) are assessed (Hair et al., 2019). As reported in Table 8.11, all reliability values exceed the minimum requirement of 0.70 (Hair et al., 2017a). Furthermore, the composite reliability does not exceed 0.95 thereby avoiding indicator redundancy (Hair et al., 2019).

Table 8.11 Reflective construct reliability and validity

Factor	α	ρ_A	CR	AVE
Attitudinal Intent to Continue Use (AI)	0.902	0.942	0.931	0.772
Delivery Performance (PB-DP)	0.881	0.891	0.913	0.678
Data Quality (PB-DQ)	0.899	0.906	0.921	0.626

Note: α = Cronbach's Alpha, CR = Composite Reliability, AVE = Average Variance Extracted.

Note: *Italics* indicate first-order factors embedded within a higher order factor.

8.3.2 Indicator Reliability

Indicator reliability is evaluated by assessing each indicator's absolute standardised loadings. Hair et al. (2019) and Chin (2010) recommend loadings should exceed 0.708 in order to explain at least 50% of the item's variance. All reflective indicator loadings are presented in Table 8.12 (see next page). As demonstrated, all loadings exceed the 0.708 threshold, with the exception of DQ06r (0.687). However, as all loadings are significant at the 0.01 level, all determinants are retained for further analysis.

Table 8.12 Reflective determinant loadings and significance

Relationship	Loading	Sig.
AI ⟶ AI01	0.962	Sig***
AI ⟶ AI02	0.822	Sig***
AI ⟶ AI03	0.946	Sig***
AI ⟶ AI04	0.757	Sig***
PB-DP ⟶ DP01r	0.850	Sig***
PB-DP ⟶ DP02	0.896	Sig***
PB-DP ⟶ DP03	0.746	Sig***
PB-DP ⟶ DP04	0.800	Sig***
PB-DP ⟶ DP05	0.818	Sig***
PB-DQ ⟶ DQ01	0.808	Sig***
PB-DQ ⟶ DQ02	0.858	Sig***
PB-DQ ⟶ DQ03	0.859	Sig***
PB-DQ ⟶ DQ04	0.845	Sig***
PB-DQ ⟶ DQ05	0.748	Sig***
PB-DQ ⟶ DQ06r	0.687	Sig***
PB-DQ ⟶ DQ07	0.715	Sig***

Note: "r" denotes reverse-coded item.

Note: *Italics* indicate a hierarchical relationship

Note: * p-value < 0.1 level. ** p-value < 0.05 level.

*** p-value < 0.01 level.

8.3.3 Convergent Validity

Convergent validity is defined as the extent to which determinants align in their representation of the latent factor (Chin, 2010). In assessing convergent validity, emphasis is placed on the Average Variance Extracted (AVE) which describes the model's ability to explain indicator variance (Wong, 2016). Hair et al. (2019) recommend that determinants should achieve 0.50 or higher to be considered satisfactory, as this would demonstrate the factor's capacity to explain more than 50% of the determinant's variance. From Table 8.11, the minimum AVE value achieved is 0.627 which therefore satisfies this requirement. Therefore, all reflective values have high levels of convergent validity.

8.3.4 Discriminant Validity

Discriminant validity seeks to assess the extent to which the determinants measure what they intend to measure (Hair et al., 2014b). For reflective factors, discriminant validity can be assessed against either the factor cross-loadings, the Fornell-Larcker criterion (Fornell and Larcker, 1981) or the Heterotrait-Monotrait (HTMT) ratio (Henseler et al., 2014). As we are dealing with a small sample size which may impact the sensitivity of analysis in addition to also handling emergent factors from the EFA, all three methods are used and discussed here.

Hair et al. (2011) emphasise that an indicator's outer loading should be higher than all of its cross loadings. As such, using the outer loadings are reported in Table 8.12 and the comparison against the cross-loadings provided in Appendix F, discriminant validity is well established according to this criteria.

In a more stringent approach, the Fornell-Larcker criterion suggests that the latent construct shares greater variance with its denominated determinants than it does with any other factor (Hair et al., 2014b). Fornell and Larcker recommend that the inter-factor correlation should be less than the square root of each factor's AVE (Fornell and Larcker, 1981). Table 8.13 presents these correlations for the reflective constructs and assigns the square root of the AVE to the diagonal. As demonstrated, all values comply with the Fornell-Larcker criterion and therefore suggests satisfactory discriminant validity.

Table 8.13 Discriminant validity: Correlation matrix and $\sqrt{AVE}$ values

	AI	**AEA**	***PB-DP***	***PB-DQ***
AI	**0.879**			
AEA	0.224	**SI**		
PB-DP	0.314	0.223	**0.823**	
PB-DQ	0.346	0.344	0.465	**0.791**

Note: *Italics* indicate first-order factors embedded within a higher order factor.

Note: $\sqrt{AVE}$ values are on the diagonal in bold. SI = Single-item Indicator.

Lastly, based on criticisms of the two aforementioned approaches, recent PLS-SEM literature has emphasised the use of the HTMT to assess discriminant validity, particularly in situations (e.g. Henseler et al., 2014; Henseler, Hubona, and Ray, 2016; Benitez et al., 2020). According to Henseler et al. (2014), the HTMT ratio examines the mean value of the determinant correlations across other latent factors (i.e. the heterotrait-heteromethod correlations) and compares it to the geometric mean of the average determinant correlations within the same latent construct (i.e. the monotrait-heteromethod correlations). High HTMT values would suggest that discriminant validity is not present. Therefore, Hair et al. (2019) recommend that the HTMT ratio should be less than 0.90 for conceptually similar constructs, and less than 0.85 for conceptually different constructs. As demonstrated in Table 8.14, the highest HTMT value is 0.511 (PB-DP) which therefore suggests that all reflective factors comfortably meet these thresholds.

Table 8.14 Discriminant validity: Heterotrait-Monotrait Ratio (HTMT)

	AI	**AEA**	***PB-DP***	***PB-DQ***
AI	-			
AEA	0.225	-		
PB-DP	0.327	0.233	-	
PB-DQ	0.355	0.361	0.511	-

Note: *Italics* indicate a first-order relationship embedded within a higher order factor.

8.4 Formative Measurement Model

As discussed in Section 7.8, PLS-SEM is the preferred approach when dealing with formative measurement models due to its ability to estimate outer weights (Chin, 2010). However, as the relationship between the manifest variables and the latent factors are structurally different to those used in reflective measurement models and do not expect to covary, traditional concepts of reliability (i.e. internal consistency) and validity (i.e. convergent and discriminant validity) do not apply (Petter, Straub, and Rai, 2007; Edwards, 2011). Instead, Hair et al. (2014b; 2019) set out alternative steps to follow in evaluating formative outer models, which are evaluating the collinearity of the outer model constructs, and determining the level of significance of each determinant via assessment of the outer weights. These analyses are conducted in SmartPLS based on the Mode A weighting scheme (Becker et al., 2013; Ringle, Wende, and Becker, 2015). Table 8.15 presents the results which are discussed in detail in the following sections.

Table 8.15 Significance of formative determinants outer weights

Item	VIF	Outer Weight	*t*-Statistic	Sig.	Outer Loading	*t*-Statistic	Sig.
EP01	1.012	0.448	0.835	NS	0.392	0.677	NS
EP02	1.059	0.776	1.673	Sig*	0.812	1.55	NS
EP03	1.052	0.358	0.914	NS	0.542	1.255	NS
FC01	1.546	0.304	3.688	Sig***	0.771	5.391	Sig***
FC02	1.458	0.463	4.438	Sig***	0.834	10.331	Sig***
FC03r	1.411	0.357	3.745	Sig***	0.754	5.293	Sig***
FC04	1.146	0.211	1.335	NS	0.522	2.029	Sig**
PU01	1.002	-0.064	0.306	NS	-0.025	0.080	NS
PU02	1.412	0.547	6.013	Sig***	0.865	9.151	Sig***
PU03	1.412	0.593	6.313	Sig***	0.886	10.993	Sig***
RP01	1.734	0.548	1.753	Sig*	0.479	1.108	NS
RP02	1.474	0.514	1.616	NS	0.613	1.545	NS
RP03	2.016	-0.586	1.340	NS	-0.548	0.848	NS
RP04	2.378	-0.329	0.908	NS	-0.309	0.508	NS
SN01	1.625	0.689	1.426	NS	0.938	2.660	Sig***
SN02	2.055	0.035	0.086	NS	0.701	2.134	Sig**
SN03	2.056	0.402	1.548	NS	0.818	2.886	Sig***

Note: "r" denotes reverse-coded item. VIF = Variance Inflation Factor, NS = Nonsignificant.

Note: * *p*-value < 0.1 level. ** *p*-value < 0.05 level. *** *p*-value < 0.01 level.

8.4.1 Collinearity Testing

Collinearity describes the extent to which the magnitude, sign, or significance of the indicator outer weights differ when compared to the bivariate correlation between the determinant and its factor (Cenfetelli and Bassellier, 2009). When high collinearity occurs, the contribution of each individual determinant can be difficult to assess in a formative setting which can, in turn, lead to unstable coefficients (Wilcox, Howell, and Breivik, 2008). Therefore, multicollinearity is assessed in this study through an examination of the Variance Inflation Factor (VIF) for each formative determinant. Hair et al. (2019) state that there are critical collinearity issues when VIF is $\geqslant 5$, and possible issues when VIF is $\geqslant 3.5$. As the highest VIF value reported in Table 8.15 is 2.378 (RP04), there are no collinearity issues within the dataset.

8.4.2 Outer Weights

The final step in assessing formative measurement models is the examination of the indicator weights' statistical significance. As a nonparametric method which does not assume normal distribution, bootstrapping is used to determine significance (Chin et al., 1998). Bootstrapping is a technique which estimates models for a large number of subsamples which are drawn from the original dataset in order to compute a standard error for each model parameter, thereby determining the significance using *t*-statistics (Hair et al., 2014b). A bias-corrected and accelerated bootstrap is therefore performed with 5,000 subsamples and the results are reported in Table 8.15. In line with the recommendations of Petter et al. (2007) and Hair et al. (2012b), the table reports the outer weights, which are presented in SmartPLS as path coefficients, and their significance in terms of *t*- and *p*-values. For the outer weights to be considered statistically significant, the *p*-value should achieve < 0.05 at a 95% confidence interval and the critical *t*-value for a two-tailed test should exceed 1.96.

As seen in Table 8.15, the outer weights for nine out of the 17 formative determinants were found to be nonsignificant. However, following Cenfetelli and Bassellier (2009), Wong et al. (2013) and Hair et al. (Hair et al., 2014b), formative items should only be considered for removal from the outer model if they exhibit both nonsignificant outer weights *and* outer loadings. Hair et al. (2019) also suggest that only items with significant absolute loadings of $\geqslant 0.500$ should be retained when dealing within nonsignificant indicator weights. This is because each formative determinant is designed to distinctly contribute to the coverage of the studied construct, unlike reflective determinants which are designed to be unidimensional, interchangeable, and representative of the studied construct (Cenfetelli and Bassellier, 2009). In other words, removal of a formative measure risks altering the theoretical structure of the factor (Hair et al., 2014b). Therefore, Table 8.15 also reports the outer loadings and their significance.

Based on these criteria, the External Pressures and Risk Propensity factors are considered for removal as none of their measures satisfy the significance measures for either outer weights or outer loadings. PU01 is also noted as a concern for this reason. Furthermore, Perceived Extent of Use and Risk Propensity have a co-occurrence of negative and positive weights which suggests they may be subject to suppression, i.e. they may share more variance with another indicator than with the factor they are intended to measure (Cenfetelli and Bassellier, 2009).

After Diamontopolous and Winklhofer (2001), nonsignificant measures are iteratively removed one at a time according to the lowest *t*-statistic for the outer loading until all values are significant at the $p < 0.05$ level and exceeds 0.500. The following determinants were removed in order: PU01, RP04, RP03, EP01, and EP03. Although EP02 returned a significant outer loading ($p < 0.01$, $t = 2.836$) and a significant outer weight ($p < 0.05$, $t = 2.353$), the External Pressures factor was dropped from the analysis due to the inability to validate EP02 as a single-item construct. All remaining determinants exhibit significant outer loadings which exceed the 0.500 threshold ($p < 0.01$ for all, except FC04 and SN02 which are significant at the 0.05 level). However, as SN02 achieved an outer weight value of < 0.100, it is argued that its removal will have a negligible effect on the Subjective Norm construct. Taking this into account, the revised matrix presenting all valid determinants is provided in Table 8.16.

Table 8.16 Statistics for the revised formative determinants

Item	VIF	Outer Weight	*t*-Statistic	Sig.	Outer Loading	*t*-Statistic	Sig.
FC01	1.546	0.302	3.648	Sig***	0.770	5.526	Sig***
FC02	1.458	0.363	4.519	Sig***	0.835	10.682	Sig***
FC03r	1.411	0.202	4.097	Sig***	0.758	5.439	Sig***
FC04	1.146	0.465	1.398	NS	0.514	2.105	Sig**
PU02	1.411	0.546	6.528	Sig***	0.866	15.136	Sig***
PU03	1.411	0.593	6.727	Sig***	0.888	17.050	Sig***
RP01	1.459	0.579	1.55	NS	0.889	3.589	Sig***
RP02	1.459	0.553	1.506	NS	0.878	3.784	Sig***
SN01	1.479	0.714	2.208	Sig**	0.943	4.746	Sig***
SN03	1.479	0.404	1.148	NS	0.810	3.557	Sig***

Note: "r" denotes reverse-coded item. NS = Nonsignificant.

Note: * *p*-value < 0.1 level. ** *p*-value < 0.05 level. *** *p*-value < 0.01 level.

As shown within Table 8.16, FC04, RP01, RP02, and SN03 exhibit nonsignificant outer weights. However, as the indiciators' outer loadings are above 0.500 as discussed, these determinants should be interpreted as absolutely important but not relatively important (Cenfetelli and Bassellier, 2009). As the constructs are derived from existing measures grounded within established theory, the indicators are retained for further analysis (Hair, Ringle, and Sarstedt, 2013).

8.4.3 Formative Second-Order Factor

The Perceived Benefits factor is the second-order construct within a reflective-formative type model, known as a Type II hierarchical latent variable model (Becker, Klein, and Wetzels, 2012). The reflective first-order factors, Data Quality and Delivery Performance, were assessed as standard reflective measurement models within Section 8.3. However, as a higher-order construct, the Perceived Benefits factor requires further consideration to ensure it is specified correctly within the structural model. Furthermore, the Perceived Benefits factor plays an endogenous, mediating role within the BAAUM, which needs to consider the interaction with its exogenous factors in addition to its first-order constructs. Based on these considerations, an extended repeated indicators approach is adopted (Becker, Klein, and Wetzels, 2012; Sarstedt et al., 2019).

To apply the extended repeated indicators approach, the BAAUM is extended and direct relationships are drawn from Perceived Extent of Use and Actual Extent of Assimilation to both of the first-order factors. Each of the determinants used to measure the first-order factors are also repeated as formative indicators to the second-order factor[4] - see Figure 8.5.

[4] As the repeated determinants are artificially used for identification purposes only, the statistics emerging from their relationship with the Perceived Benefits factor do not need to be evaluated (Sarstedt et al., 2019)

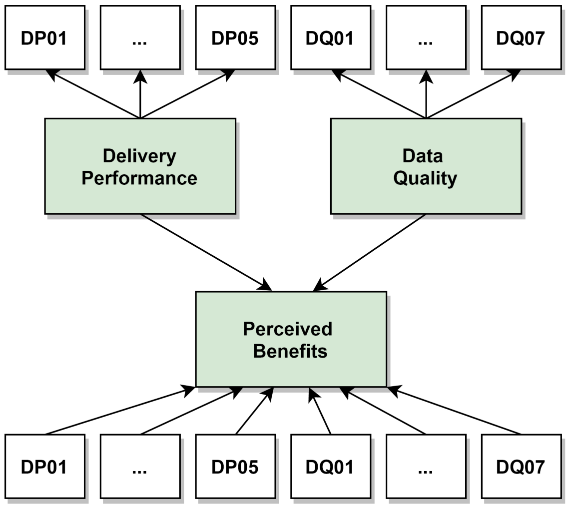


Figure 8.5 Repeated indicators in a Type II hierarchical latent variable model setting

The extended model schematic is illustrated in Figure 8.6. Following Becker et al (2012), Mode B with the inner path weighting scheme is used to estimate the measurement model of Perceived Benefits.

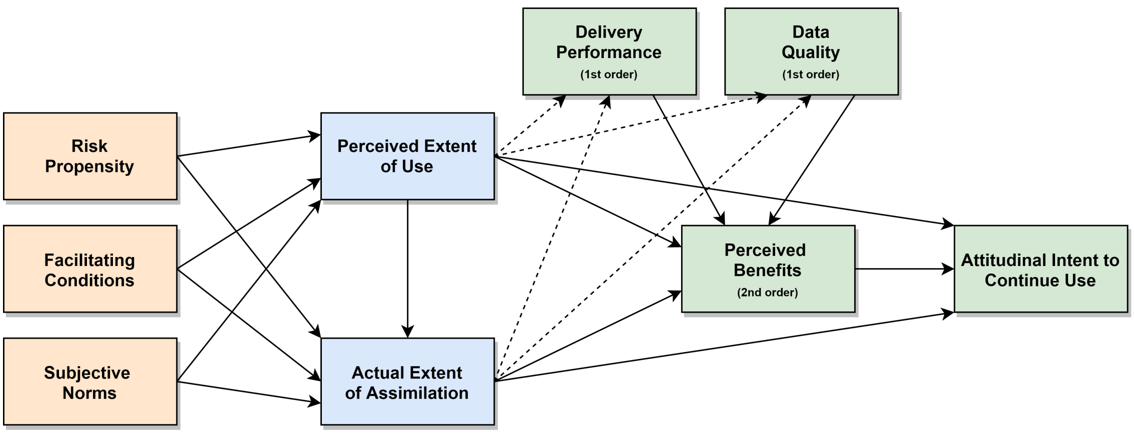


Figure 8.6 Extended repeated indicator approach for the second-order factor within the revised BAAUM. *Note:* The dashed lines represent the additional paths required to consider the factor as an endogenous variable in a higher-order setting.

Following the steps for a first-order formative measurement model, the second-order model is first assessed for collinearity issues. The analysis of the model shown in Figure 8.6 produces VIF values of 1.347 for Delivery Performance and 1.399 for Data Quality which satisfies the < 3.5 criterion (Hair et al., 2019). A bootstrapping procedure with 5,000 subsamples is then run to assess the significance of the relationships between the first-order factors and Perceived Benefits. These results are presented in Table 8.17. As illustrated,

Table 8.17 Significance of second-order formative factor outer weights

Relationship	VIF	Outer Weight	*t*-Statistic	Sig.	Outer L'ing	*t*-Statistic	Sig.
PB-DP ⟶ PB	1.347	0.468	1.343	NS	0.763	3.614	Sig***
PB-DQ ⟶ PB	1.399	0.613	2.098	Sig**	0.839	6.735	Sig***

Note: VIF = Variance Inflation Factor, NS = Nonsignificant, L'ing = Loading.

Note: * *p*-value < 0.1 level. ** *p*-value < 0.05 level. *** *p*-value < 0.01 level.

it is found that the outer weight of the relationship between Delivery Performance and Perceived Benefits is 0.468 and nonsignificant ($p = 0.179$, $t = 1.343$). However, the weight of the relationship between Data Quality and Perceived Benefits is 0.613 and significant at the 0.05 level ($p = 0.036$, $t = 2.098$). Moreover, both factors exhibit strong outer loadings ($p < 0.01$), thereby positioning the second-order factor as a valid construct within the model.

Finally, to prepare the Perceived Benefits construct for further analysis, the reliability of the formative second-order construct is calculated and specified within the model in SmartPLS. To calculate the reliability, the composite reliability scores of the first-order factors are averaged ($\frac{0.913+0.921}{2} = 0.917$) and manually input into the Perceived Benefits factor.

8.5 Evaluation of the Structural Model

Evaluation of the structural model concerns the testing of the hypothesised relationships between latent factors. In an assessment of a structural model, the path coefficients between factors are examined for effect size and significance. Similar to the approach employed within the assessment of the formative measurement models, the assessment of the structural model employs a collinearity assessment and a bootstrapping procedure to assess the significance of the outer weights (Henseler, Hubona, and Ray, 2016; Hair et al., 2019). Additionally, the statistical significance of the path coefficients based on indirect and total effects and the coefficients of determination (R^2) are also assessed.

8.5.1 COLLINEARITY ASSESSMENT

The first step in assessing the inner model involves the examination of potential collinearity issues for the exogenous factors. Similar to the approach used for the evaluation of the formative measurement models, collinearity testing relies on the VIF value not exceeding 5, with a preferable value of < 3.5. As illustrated in Table 8.18, the collinearity assessment for exogenous factors shows that all VIF values are satisfactory.

Table 8.18 Collinearity assessment for the structural model

Relationship	**VIF**
RP $\longrightarrow$ PEU	1.564
RP $\longrightarrow$ AEA	1.236
FC $\longrightarrow$ PEU	1.155
FC $\longrightarrow$ AEA	1.373
SN $\longrightarrow$ PEU	1.235
SN $\longrightarrow$ AEA	1.125
PEU $\longrightarrow$ AEA	1.289
PEU $\longrightarrow$ PB	1.699
PEU $\longrightarrow$ AI	1.695
AEA$\longrightarrow$ PB	1.598
AEA $\longrightarrow$ AI	1.564
PB $\longrightarrow$ AI	1.222

Note: VIF = Variance Inflation Factor.

8.5.2 GOODNESS OF FIT

PLS-SEM fits the model to the sample data by maximising the explained variance of the endogenous latent factors in order to obtain the best parameter estimates. This variance is measured by the coefficient of determination (R^2) which explains the model's explanatory power (Rigdon, 2012). Therefore, in line with the recommendations of Henseler et al. (2016) and Hair et al. (2017a; 2019), the inner model is evaluated based on the R^2 value. The R^2 values and the associated statistics for the four endogenous constructs are reported in Table 8.19.

Table 8.19 Coefficients of determination (R^2)

Factor	R^2	*t*-Statistic	Sig.
Attitudinal Intent to Continue Use (AI)	0.380	3.137	Sig***
Actual Extent of Assimilation (AEA)	0.392	3.908	Sig***
Perceived Benefits (PB)	0.882	12.310	Sig***
Perceived Extent of Use (PEU)	0.224	1.931	SIg**

Note: R^2 = Coefficient of Determination.

Note: * *p*-value < 0.1 level. ** *p*-value < 0.05 level. *** *p*-value < 0.01 level.

Generally speaking, a threshold value of 0.19, 0.33, and 0.67 are often used to describe weak, moderate, and substantial coefficients respectively (Chin et al., 1998), with those exceeding 0.90 deemed indicative of model overfit (Hair et al., 2019). However, the acceptability of the R^2 value is highly contextual and can vary between research domains. Moreover, the R^2 value is a function of the number of predictor constructs and therefore increases with a greater number of predictor constructs. This effect is evident in the work of Ahuja et al. (2016) who found BIM Adoption to have an R^2 value of 0.617 when predicted by eight factors, whereas the Trust and Performance factors which were both predicted by a sole construct achieved R^2 values of 0.269 and 0.210 respectively. Within BIM adoption research, R^2 values achieving 0.30 to 0.50 are considered "relatively substantial" (e.g. Cao, Li, and Wang, 2014b; Song et al., 2017; Wang and Song, 2017).

Based on these thresholds, the following conclusions can be drawn: the three antecedent factors explain 32.2% (substantial) and 22.4% (moderate) of the variance in the Actual Extent of Assimilation and Perceived Extent of Use respectively. In turn, Actual Extent of Assimilation and Perceived Extent of Use, in addition to Delivery Performance and Data Quality, explains 88.2% (very substantial) of variance in the second-order Perceived Benefits factor. Lastly, 38% (substantial) of the variance in Attitudinal Intent to Continue Use is explained by Perceived Benefits, Perceived Extent of Use, and Actual Extent of Assimilation.

8.5.3 PATH COEFFICIENTS: DIRECT EFFECTS

The next step in the inner model analysis concerns the assessment of the size and significance of the path coefficients (Hair et al., 2019). This determines the scale and importance of the direct relationships between latent factors. In line with the technique used to assess the appropriateness of the formative measurement model, bootstrapping is used to calculate the significance of the path coefficients. The results are reported in Table 8.20 which provides the path coefficients (β) and the associated significance statistics.

Table 8.20 Structural model with path coefficients

Relationship	β	*t*-Statistic	Sig.
RP ⟶ PEU	0.023	0.136	NS
RP ⟶ AEA	-0.132	0.140	NS
FC ⟶ PEU	0.412	2.957	Sig***
FC ⟶ AEA	0.228	1.577	Sig**
SN ⟶ PEU	0.162	1.108	NS
SN ⟶ AEA	0.037	0.245	NS
PEU ⟶ AEA	0.511	4.312	Sig***
PEU ⟶ PB	0.409	2.696	Sig***
PEU ⟶ AI	-0.135	1.136	NS
AEA⟶ PB	0.116	0.576	NS
AEA ⟶ AI	0.175	0.994	NS
PB ⟶ AI	0.631	6.768	Sig***

Note: β = Path Coefficient, NS = Nonsignificant.

Note: Highlighted rows indicate total effect is used.

Note: * $p < 0.1$ level. ** $p < 0.05$ level. *** $p < 0.01$ level.

The results demonstrate that four out of the twelve identified relationships are significant ($p < 0.01$). It is found that Facilitating Conditions has a positive relationship with the Perceived Extent of Use ($\beta = 0.412$, $t = 2.957$) yet does not influence Actual Extent of Assimilation. Moreover, Risk Propensity and Subjective Norms have nonsignificant relationships with both factors, despite their theoretical and practical grounding. However, a significant relationship is found between Perceived Extent of Use and Actual Extent of Assimilation ($\beta = 0.511$, $t = 4.312$) and also between the second-order Perceived Benefits factor and Attitudinal Intent to Continue Use ($\beta = 0.631$, $t = 6.768$).

To account for the extended repeated indicator approach discussed in Section 8.4.3, the total effects of the Perceived Extent of Use and Actual Extent of Assimilation on Perceived Benefits are analysed rather than the direct effects (Sarstedt et al., 2019). Applying this approach, we find that Perceived Extent of Use has a significant total effect on Perceived Benefits ($p < 0.01$, $t = 2.696$), while Actual Extent of Assimilation is nonsignificant. These relationships are highlighted within Table 8.20 and illustrated in a simplified results presentation in Figure 8.7 (see next page).

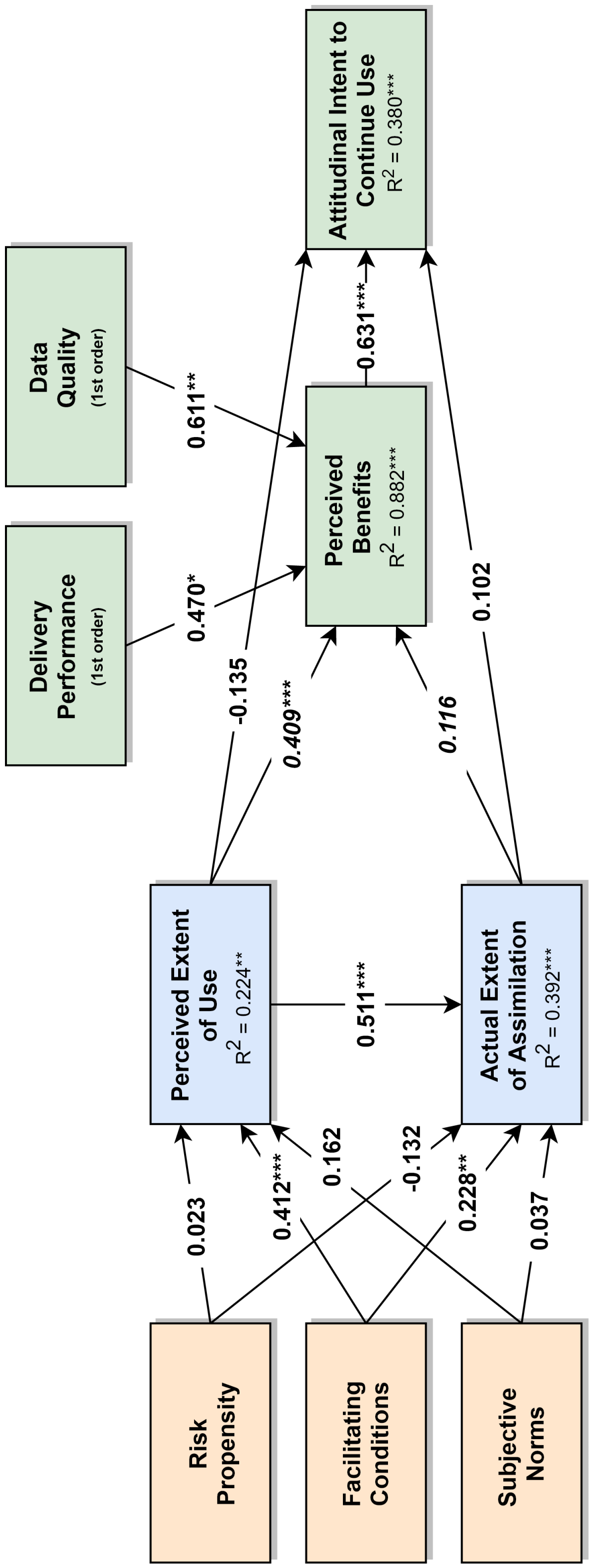


Figure 8.7 Revised BAAUM with R^2 values and direct effect path coefficients. *Note:* * $p < 0.1$ level. ** $p < 0.05$ level. *** $p < 0.01$ level. *Italics* indicate total effect from extended repeated indicator approach.

8.5.4 Path Coefficients: Indirect Effects

A mediator describes the role of a factor which is positioned in a causal chain between two other factors (Lowry and Gaskin, 2014; Nitzl, Roldán, and Cepeda, 2016). These relationships are illustrated in Figure 8.8. To test for a mediated relationship, the total indirect effect between the endogenous and exogenous factors under study is calculated by subtracting the product of direct effect A (β_A) and direct effect B (β_B) from the total effect (β_T). However, it should be noted that the role of higher-order constructs as mediators is not yet fully understood (Sarstedt et al., 2019). With this in mind, this study tests for full mediation in the Perceived Benefits factor by controlling for the direct mediated effects resulting from the extended repeated indicators approach.

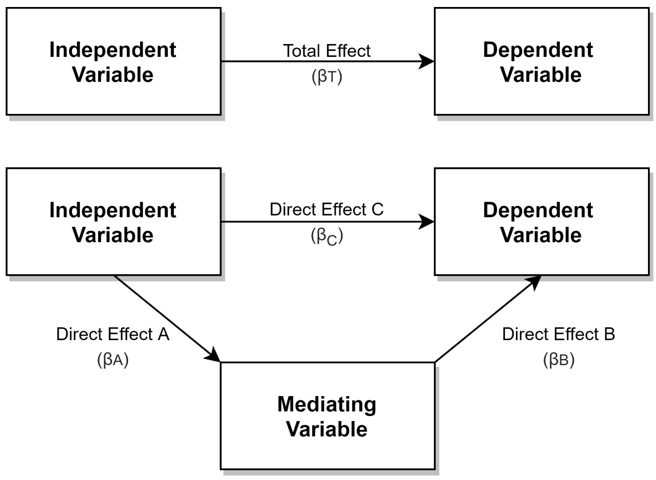


Figure 8.8 Example of a mediating variable and the direct and indirect effects

From Figure 8.7, there are three indirect relationships hypothesised within the BAAUM: 1) Actual Extent of Assimilation is proposed to have an indirect effect on Attitudinal Intent to Continue Use, mediated by Perceived Benefits, 2) Perceived Extent of Use is proposed to have an indirect effect on Attitudinal Intent to Continue Use, mediated by both Perceived Benefits and Actual Extent of Assimilation, and 3) Perceived Extent of Use is proposed to have an indirect effect on Perceived Benefits, mediated by Actual Extent of Assimilation. As done elsewhere in this study, bootstrapping is applied to assess the significance of these relationships (Chin, 2010). Accordingly, the indirect effects are reported in Table 8.21.

Table 8.21 Mediating path coefficients and indirect effects

Relationship	$\beta_{indirec}$	***t*-Statistic**	**Sig.**
PEU $\longrightarrow$ PB	0.373	2.646	Sig***
PEU $\longrightarrow$ AI	0.310	2.019	Sig**
AEA $\longrightarrow$ AI	0.073	0.456	NS

Note: β_C = Path Coefficient (Indirect Effect), NS = Nonsignificant.

Note: * $p < 0.1$ level. ** $p < 0.05$ level. *** $p < 0.01$ level.

Table 8.21 demonstrates a significant indirect effect between Perceived Extent of Use and Perceived Benefits ($p < 0.01$, $t = 2.646$) and between Perceived Extent of Use and Attitudinal Intent to Continue Use ($p < 0.05$, $t = 2.019$). The indirect effect between Actual Extent of Assimilation and Attitudinal Intent to Continue Use is nonsignificant. However, it is important to note that the total effect between Perceived Extent of Use and Perceived Benefits will also account for the indirect effects arising from the extended repeated indicator approach in which the first-order Delivery Performance and Data Quality factors are also positioned as mediators - see Figure 8.6. Moreover, as the direct relationship between Actual Extent of Assimilation and Perceived Benefits (β_B in this scenario) is also nonsignificant, Actual Extent of Assimilation cannot be said to mediate the relationship, either partially or fully, between Perceived Extent of Use and Perceived Benefits. Lastly, as the paths represent a direct effect in accordance with the schematic set out in Figure 8.8, the total effects as stated in Table 8.20 can be applied within the mediation analyses for Perceived Extent of Use and Actual Extent of Assimilation on Attitudinal Intent to Continue Use.

8.5.5 Moderating Effect

As explored in Chapter SIX, Voluntariness of Use is suggested to act as a moderating variable. To test moderator effects statistically, relationships are checked for interaction effects among the factors (Lowry and Gaskin, 2014). Therefore, using the product indicator calculation approach within SmartPLS (Ringle, Wende, and Becker, 2015), each endogenous factor was iteratively assigned the Voluntariness of Use construct and, applying the one-tailed test, examined for a significant moderating effect based on its relationship with its predictors. However, in all instances, the moderating effect was found to be nonsignificant.

8.6 Summary of Hypothesis Testing

In this study, the null hypothesis is rejected if the *p*-value < 0.10 using a one-tailed test. To guide the summary, Figure 8.9 presents an overview of the significant and insignificant paths.

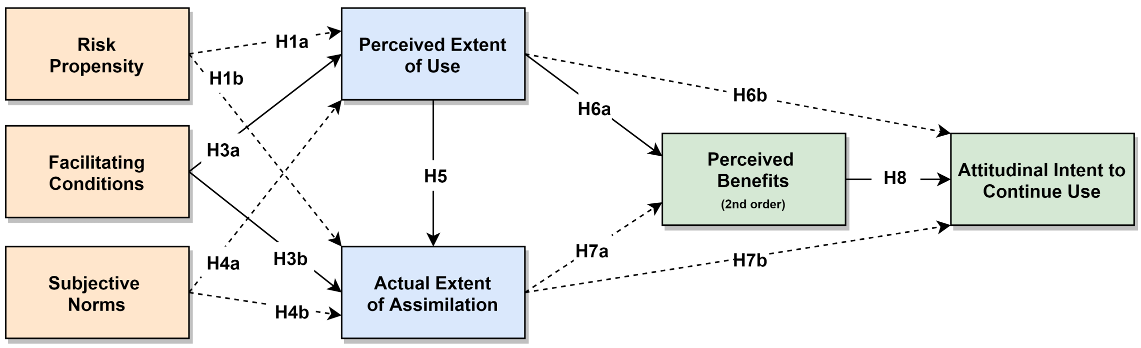


Figure 8.9 BAAUM displaying all significant and insignificant paths. Note: Dashed lines indicate nonsignificant paths. External Pressures has been omitted for clarity.

Based on the revised set of hypotheses presented in Section 8.1.5, the results for the testing of the antecedent hypotheses are summarised in Table 8.22. Out of the eight hypotheses developed and revised to test the relationship between the antecedent drivers and the focal constructs, only H3a and H3b were supported. In other words, Facilitating Conditions was found to have a significant effect on both the individual's Perceived Extent of Use and their Actual Extent of Assimilation. On the other hand, Risk Propensity and Subjective Norms were found not to have a significant effect on either Perceived Extent of Use or Actual Extent of Assimilation. The lack of support for the Risk Propensity factor is perhaps not surprising; rather than drawing on well-established constructs within theory, the Risk Propensity factor was informed by practical discussions and by drawing on discussions surrounding general risk in adopting BIM, rather than focusing on an individual's own perceptions of risk.

Table 8.22 BAAUM hypothesis testing: Antecedent drivers

	Hypothesis	Supported?
H1a	The individual's risk propensity in construction projects is positively associated with their perceived extent of use.	**Rejected**
H1b	The individual's risk propensity in construction projects is positively associated with their actual extent of BIM assimilation.	**Rejected**
H2a	There is a positive relationship between external pressures and an individual's perceived extent of use of BIM.	Not tested
H2b	There is a positive relationship between external pressures and an individual's actual extent of BIM assimilation.	Not tested
H3a	Facilitating conditions have a positive influence on an individual's perceived extent of use of BIM.	**Supported**
H3b	Facilitating conditions have a positive influence on an individual's actual extent of assimilation of BIM.	**Supported**
H4a	The subjective norms are positively related an individual's perceived extent of BIM use.	**Rejected**
H4b	The subjective norms are positively related an individual's actual extent of BIM assimilation.	**Rejected**

However, the same cannot be said for Subjective Norms as this factor is well-established in IS-theory. The rejection of the hypothesis may be predicated on the inconsistent measures applied in attempting to understand the construct, which in turn, may affect the ability of the identified determinants to appropriately capture the underlying latent construct. For example, the discussion presented in Chapter SIX highlights that Subjective Norms have often been interspersed with conversations regarding normative beliefs and other pressure-types drawn from Institutional Theory. This reasoning is likely also to apply to the External Pressures factor. The External Pressures construct was not tested due to its elimination from the model during the testing of the measurement models.

Table 8.23 presents the results of the hypothesis testing for H5 to H8 inclusively. Out of the six hypothesised relationships, H5, H6a, and H8 were confirmed. Perceived Extent of Use was found to have a positive impact on the Actual Extent of Assimilation. This suggests that the more an individual perceives themselves to be using BIM, the more they have actually assimilated it. Perceived Extent of Use was also found to have a positive influence on the second-order Perceived Benefits construct, which in turn has a positive

Table 8.23 BAAUM hypothesis testing: Focal constructs and perceived use outcomes

	Hypothesis	Supported?
H5	An individual's perceived extent of use of BIM has a direct relationship with their actual extent of assimilation.	**Supported**
H6a	There is a direct relationship between perceived extent of use and perceived benefits.	**Supported**
H6b	There is a direct relationship between perceived extent of use and attitudinal intent to continue use.	**Rejected**
H7a	There is a direct relationship between actual extent of assimilation and perceived benefits.	**Rejected**
H7b	There is a direct relationship between actual extent of assimilation and attitudinal intent to continue use.	**Rejected**
H8	The perceived benefits have a positive influence on the individual's attitudinal intent to continue use..	**Supported**

relationship with Attitudinal Intent to Continue Use. Whilst it appears that Perceived Benefits fully mediates the relationship between Perceived Extent of Use and Attitudinal Intent to Continue Use, this also accounts for the mediating effects of the first-order Data Accuracy and Data Reliability factors. With this in mind, Perceived Benefits can be said to partially mediate the relationship between Perceived Extent of Use and Attitudinal Intent to Continue Use when accounting for the total effect in play for the H6a path.

Surprisingly, Actual Extent of Assimilation had nonsignificant effects on both the Perceived Benefits and Attitudinal Intent to Continue Use factors, thereby rejecting both H7a and H7b. However, there is strong evidence that the more an individual perceives there to be benefits from using BIM, the more positive they will feel toward their own continuance behaviour. This aligns with the tenet promoted by the Information Systems Success Model.

8.7 Concluding Remarks

This chapter has presented the data analysis and results for Phase II of the study. In response to the achieved sample size, an Exploratory Factor Analysis was first conducted to reduce the dimensionality of the BAAUM. Nine reflective factors were reduced to three emergent factors which demonstrated strong validity and reliability characteristics. A revised BAAUM was then presented in response to the EFA findings. Attention was then turned to the assessment of the measurement models as part of the PLS-SEM procedure. Three types of outer model were examined: the dichotomous measurement model, the reflective measurement model, and the formative measurement model. All outer models were assessed against established quality criteria and refined accordingly. Finally, the structural model was examined and the hypotheses within the revised BAAUM tested. The next and final chapter within this thesis will discuss the results presented here within the context of the research objectives and conclude the study.

CHAPTER NINE

DISCUSSION AND RESEARCH CONCLUSIONS

This chapter presents the departing thoughts of the study. It reintroduces the research aim and outlines how each of the research objectives were addressed according to the research design. The contributions of the study are also discussed, by outlining the contribution to theory and the implications on practice and in policy. The present study was not without limitations, which are discussed along with recommendations on how to address these shortcomings in future work. Considering the infancy of the UK's digital construction journey, the exploratory nature of the work situates this research as an initial stage in a wider research discourse. Therefore, this chapter concludes with how this thesis sits within a potential research landscape, based on the implications of the findings and the directions for the next stages of inquiry. The research objectives and how they have been addressed are provided in Table 9.1.

Table 9.1 Methods used to achieve the Research Objectives

	Research Objectives	Literature Review	Phase I	Phase II
RO1	To interrogate the perceived rate of BIM adoption from a multi-level perspective.	✓	✓	
RO2	To critically review the most common models and theories related to Information Systems (IS)-based innovation acceptance, assimilation, and use by appraising their contributions and applicability to BIM.	✓		
RO3	To develop and propose an integrative framework for micro-level BIM use behaviour.	✓	✓	✓
RO4	To utilise the proposed model to analyse the influence of the identified micro-levels factors on BIM use behaviours.			✓

9.1 ACHIEVEMENT OF THE RESEARCH OBJECTIVES

The aim of this study was to explore and investigate the role of micro-level factors on achieving an effective macro-level diffusion of Building Information Modelling (BIM) in the UK.

9.1.1 RESEARCH OBJECTIVE 1

The first Research Objective (RO1) was to interrogate the perceived rate of BIM adoption and maturity from a multi-level perspective. In order to comprehensively address RO1, this thesis first considers the contribution of assuming a multilevel lens through which to study BIM adoption within the context of the research problem. RO1 was addressed in exploratory terms through the literature review in Chapter TWO and in theoretical terms in Chapter FIVE. First, the concept of BIM adoption was delineated and clarified in Chapter TWO by positioning the present study within an emerging but comprehensive BIM adoption taxonomy and by renewing calls for embracing a unified ontology. When discussing the implications of this unified ontology, Chapter TWO also introduced the concept of so-called scales of investigation, which pertains to whether BIM adoption is studied at the level of the individual (micro), at the level of the organisation or project (meso), or at the level of industry (macro). By using these defined levels as a frame of reference, the current state of BIM adoption research can be better understood by identifying prevalent gaps in knowledge and providing a targeted research response as appropriate. This framed the initial focus on national, or macro-level, BIM adoption.

However, the literature review also developed a dialogue predicated on the interaction between levels. As reiterated in Section 5.2, a micro-macro relation exists in which BIM diffusion at the macro-level is influenced by the adoption activities of organisations and projects at the meso-level, which is in turn reliant on the collective behaviour of individuals at the micro-level. Accordingly, Chapter FIVE considered the theoretical implications of assuming a multilevel perspective. It was found that within the social sciences the so-called micro-to-macro problem oftentimes presents itself as a caveat to developing an effective understanding of the relationship between the constituents of a social system (i.e.

the micro-level) and wider social phenomena (i.e. the macro-level). However, drawing on long-standing debates spearheaded by sociologist James Coleman (1986) and led in the IS-domain by Tscherning (2011), this study followed the methodological individualism school of thought to structure the conceptual framework. To summarise, a multi-level social sciences perspective was applied within this study as follows:

- By applying an established BIM adoption taxonomy, we aligned adoption terms to the levels of analysis to frame the inter-level discussions emerging from the literature review. To differentiate between the micro- and macro-perspectives, the term *adoption* was replaced with the terms *implementation* and *diffusion* respectively.

- Following the methodological individualism principles, the study embraced the Multilevel Framework for Technology Adoption (Tscherning, 2011) to inform theory construction. To do so, the conceptual framework was developed by applying a macroperspective of the UK's BIM hypothesis which was then extrapolated to focus on measurement of the microphenomena. By approaching the conceptual discussions in this manner, the work was informed by real-world policy, vis-á-vis the BIM hypothesis, and also by the extensive body of micro-level study in which the much of the theoretical foundations surrounding technological innovation adoption are grounded.

- Chapter FOUR further developed the narrative of interacting levels of analysis by using the micro- and macro-perspectives as key themes to frame the focus group discussions.

- The literature review in Chapter FIVE also used the level of analysis as a lens to examine technological innovation adoption theories and models applicable to BIM. By doing so, we identified the strengths and weaknesses prevalent within the prescribed theoretical frameworks as applicable to the present study.

Next, the thesis challenges how the rate of BIM adoption is interpreted and measured, which is addressed by the literature review in Chapter TWO. The emerging narrative of the literature review was validated by the focus group interviews in Chapter FOUR. First, the literature review discussed the role of innovations within a construction context, before extending the appraisal of BIM as a systemic innovation to one of a multifaceted nature to capture its many constituent parts. Considering the sector's strained history with innovation as outlined in Chapter ONE, the diffusion of BIM faces significant challenges which can only be realistically addressed through strong, coordinated efforts driven by government. The literature review then discussed the UK's approach to BIM diffusion through the lens of diffusion mechanisms (Rogers, 2003; Succar and Kassem, 2015).

However, appraisal of BIM from an innovation perspective has led to many scholars approaching BIM adoption as a dichotomous decision-making activity. This is particularly prevalent in Information Systems (IS)- based theory; Chapter FIVE highlighted a tendency to interpret BIM as a simple, bounded technology when attempting to measure its adoption and use and thereby applying inappropriate measures better suited to the study of individual technological artefacts. In reality, BIM requires significant investment in both human and financial capital for effective, coordinated adoption, which may result in the adoption of individual modules being approached in a building-block manner.

The prevailing outcome of this discussion was that the difficulty in assessing innovation diffusion in the AECO industry is translating into inadequate attempts to study industry-scale BIM adoption. The attempts that have been conducted, however, should not be wholly discredited as they highlight a gap in knowledge considering the role of micro-level behaviour in BIM diffusion. In other words, whilst annual figures published by the NBS suggest a positive trend in macro-level BIM uptake, nuances within the data suggest this may be obscuring the existence of an assimilation gap effect. It is likely that this is attributed to the multifaceted system structure of BIM, in which its adoption would comprise of several interrelated decision-making processes which would each exhibit their own diffusion patterns.

Finally, literature and industry opinion suggests this purported effect may also be indicative of a suboptimal approach to widescale upskilling and assimilation. The present model of AECO education and training is being challenged by the emergence of systemic changes which not only concern digital technologies, but also sustainability and green agendas. Notably, such systemic process changes need to be communicated to two audiences: current industry professionals, and education and training providers who will be influencing future industry professionals. However, as reinforced by the focus group interviews in Chapter FOUR, whilst isolated efforts do exist to satiate an immediate need, there is a lack of consistency and standardisation across delivery which leads to patchy upskilling practices across an already diversified industry.

Therefore, the key issues surrounding current understanding of how the rate of BIM adoption is assessed can be summarised as follows:

- Current macro-level BIM adoption assessments are insufficient, with increasing reliance on commercial surveys which has led to them acting as a proxy for macro-level diffusion. Yet, such surveys are methodologically ambiguous and therefore cannot be considered as robust tools.
- These industry-led measurements do not consider the overall efficacy of national BIM adoption, when literature suggests that the political emphasis is on the public-sector rather than whole industry adoption which risks ineffective, patchy diffusion.
- Crude examination of the data published by commercial bodies suggests that gaps exist between promoted rhetoric and apparent reality which has not yet been explored in detail, nor in a BIM capacity.
- BIM adoption assessments generally do not consider the role of upskilling and competence. Instead, there is a reliance on ineffective use behaviour measures which do not align with our understanding of BIM as an innovation.

9.1.2 Research Objective 2

The second objective (RO2) sought to critically review the most common models and theories related to Information Systems (IS)-based innovation use behaviour by appraising their contributions and applicability to BIM. As briefly touched upon in the response to RO1, BIM adoption scholars are looking to IS research to inform their understanding of innovation adoption. Therefore, to answer the second research objective, a second literature review was conducted within Chapter FIVE. It was found that the technological connotations of BIM has led to a small but emerging group of literature starting to use theoretical frameworks borne from IS innovation research as a lens through which to understand BIM adoption. The influence of the IS domain within BIM adoption and use research is particularly evident when studying the application of a unified BIM taxonomy and when considering BIM within a broader sociotechnological innovation context.

Building on this narrative, Chapter FIVE presented a broad overview of this important body of work and used it to frame the discussion surrounding which models and theories are being applied within the BIM arena. It was found that studies seem to converge on a core set of theoretical models and frameworks, including the Diffusion of Innovations (DOI) theory, the IS Success Model (ISSM), and the various iterations of the technology acceptance model (TAM) family. The review highlighted that there is very little consensus surrounding how such theories are applied to BIM adoption, with most authors applying a "pick and mix" approach to theory construction. However, many were found to advocate this configurable approach to theory development, particularly when considering the inter-domain connotations and novel workflows associated with the BIM process.

Moreover, this study argued that IS-based innovation adoption models are generally better suited to explaining the acceptance and utilisation of incremental innovations, rather than systemic, multifaceted innovations such as BIM. This is perhaps not surprising as many of the theoretical models and frameworks have been developed to consider the adoption behaviour surrounding a single, bounded technological artefact such as individual software tools. Whilst this may provide insight into the individual modules of BIM, this theoretical approach runs the risk of drawing erroneous results when considered from a holistic perspective. However, many of the constructs and relationships promoted by these theories have successfully been applied in previous BIM adoption and use research and should therefore not be automatically discounted. Rather, the relationships promoted by existing theory should be appraised and contextualised appropriately.

To do so in the present research, each of the identified theories and models were introduced and their applicability and contribution to BIM adoption and use behaviour evaluated. The review drew on the studies identified within the constructed theory matrix and on the multi-level narrative which was utilised as a framing device for the study. Based on these discussions, an IS-based innovation approach which is built on these existing theoretical foundations can contribute to the study of BIM adoption and use as follows:

- IS-based technology acceptance and use theory is a well-established arena, thereby presenting a solid foundation on which to explore the use of existing constructs and relationships, particularly in exploratory research. This approach has already been adopted by several BIM scholars and represents a growing area of interest in the field.
- One can build on the existing synergies between the two domains by further contributing to and refining a unified BIM taxonomy.
- The limitations of existing theory have been extensively documented, thereby providing several theoretical departure points based on existing prescriptions.
- In relation to the above point, the nuances of BIM as a systemic, sociotechnological construction innovation may also provide novel insights into the IS and innovation adoption fields. This means that despite its extensive catalogue the IS field has not stagnated and contributions can still be made to the field. Therefore, ongoing research may yet bring further understanding to the adoption of systemic, modular innovations.

9.1.3 Research Objective 3

The third research objective was to develop and propose an integrative framework for micro-level BIM use behaviour. Research Objective 3 (RO3) was met through an extensive review of the literature in Chapter FIVE and through construction of the conceptual framework in Chapter SIX. RO3 sought to better understand the contribution and applicability of IS-based innovation adoption research to BIM use behaviour by using the premise established by RO2 and assuming a bottom-up approach to theory development. This describes the process in which the constructs and their proposed relationships are used to inform the model construction process. Two angles to theory development were identified: 1) the identification of key constructs from within established theory and empirical BIM adoption and use behaviour research, and 2) the development of novel constructs which could address the emergent gaps identified within the literature review.

In order to utilise a configurable approach to theory construction, the key micro-level constructs were identified using an integrative framework built upon the macro-level UK BIM hypothesis. This allowed the relationships between constructs to emerge organically based upon the practical underpinnings of the UK's BIM discourse and by utilising the relationships supported both theoretically and empirically in research settings. The integrative framework revealed three core sets of factors; the antecedent drivers, the focal constructs, and the perceived use outcomes. These factors and their associated constructs are illustrated in Figure 9.1. The full integrative framework is illustrated in Figure 6.8.

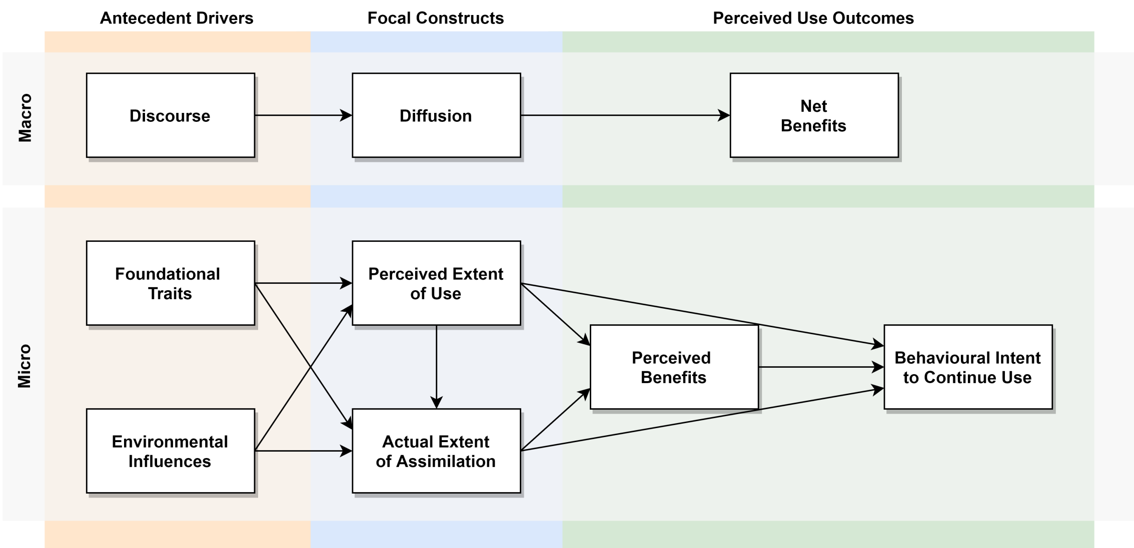


Figure 9.1 Relationship between the BAAUM and the macroperspective framework

Therefore, based on extant BIM adoption literature as explored in Chapter FIVE and building on relevant relationships from within IS theory, the following key constructs were conceptualised and used within the present study as follows:

- **Foundational Traits** which consider the individual's personal attributes, namely Attitude Toward BIM, Self-Efficacy, and Risk Propensity.

- **Environmental Influences** which concern the characteristics external to the individual, including External Pressures, Facilitating Conditions, Subjective Norms, and Top Management Support.
- **Perceived Benefits** which is conceptualised as a second-order factor and encompasses Client Satisfaction, Improved Coordination, Task Productivity, Data Accuracy, and Data Reliability.
- **Behavioural Intent to Continue Use** which is the last perceived use outcome and describes the individual's continuance intent.

Where possible, existing measures were borrowed from seminal work to retain content validity. However, the study also presented a case for considering two novel constructs which are grounded on the narrative presented by the literature review. These novel constructs are as follows:

- **Perceived Extent of Use** which considers the self-reported use behaviour of individuals. Although not strictly new to the IS domain, the terminology used emphasises the self-perceived nature of the construct, rather than acting as a proxy for absolute adoption and use behaviour which is the standard approach in many theoretical applications.
- **Actual Extent of Assimilation** which measures the *actual* extent of use by framing it according to an individual's level of assimilation. The research therefore attempts to understand the difference between an individual's perceived and actual use behaviour.

9.1.4 RESEARCH OBJECTIVE 4

The fourth and final research objective was to utilise the proposed model, the BAAUM, to analyse the influence of the identified micro-levels factors on BIM use behaviours. Research Objective 4 (RO4) was addressed during Phase II of the research in Chapters SEVEN and EIGHT. Although the descriptive statistics provided useful insights into the respondents' perception of the individual constructs, the PLS-SEM analysis provided a deeper insight into the causal relationships between the antecedent drivers and their outcome constructs, Perceived Extent of Use and Actual Extent of Assimilation.

The PLS-SEM analysis revealed that the Facilitating Conditions construct was the only one to have a significant influence on Perceived Extent of Use and on Actual Extent of Assimilation. Moreover, as all four determinants aiming to measure the Facilitating Conditions factor were retained, this suggests the proposed measures adequately captured the latent construct. Furthermore, the findings suggest that individuals generally perceive themselves to be supported in their use and assimilation of BIM through accessible resources and assistance.

Following the refinement of the model and achieving the desired dimensionality reduction through the EFA, only two other antecedent drivers were assessed. These were Risk Propensity and Subjective Norms, which were found to be insignificant predictors of Perceived Extent of Use and Actual Extent of Assimilation. However, numerous other causal relationships were initially theorised and were found to be generally favourable when subjected to descriptive analysis in Chapter SEVEN. Therefore, discussion on the reduction of factors, sample size, and the inability to test all original causal relationships is provided in Sections 9.3 and 9.4. The below points summarise the findings:

- Facilitating Conditions have a positive influence on an individual's perceived extent of BIM use.
- Facilitating Conditions have a positive influence on an individual's actual extent of BIM assimilation.

RO4 also considered the causal relationships between the focal constructs (i.e. the micro-level use behaviour) and the perceived use outcomes. Within the BAAUM, *micro-level use behaviour* encompasses both the Perceived Extent of Use and the Actual Extent of Assimilation factors. The study found that Perceived Extent of Use has a positive influence on both Actual Extent of Assimilation and on Perceived Benefits. On the other hand, Actual Extent of Assimilation was found to have no causal effect on any construct. However, the hypothesis between Perceived Extent of Use and Actual Extent of Assimilation was supported.

9.2 Contribution to Knowledge

The present study has provided numerous contributions to theoretical and practical knowledge. This section outlines these contributions within the context of BIM adoption and use behaviour and IS innovation research.

9.2.1 Theoretical Contributions

With regard to situating the study within the emerging BIM adoption domain, the theoretical contributions of the research can be summarised as follows:

1. This study has sought to further establish the use of a unified ontology surrounding BIM adoption by embracing the terminology promoted by the Unified BIM Adoption Taxonomy (Ahmed and Kassem, 2018). By using standardised language to discuss adoption model constructs, the field of BIM adoption research can be better studied in terms of bibliometrics and growth opportunities, such as the methods applied by Li et al. (2017) and Santos et al. (2017).

2. Secondly, the study has provided a micro-level perspective of the assimilation gap, as conceptualised by Fichman and Kemerer (1999), by drawing on BIM's appraisal as a systemic, modular innovation (Taylor and Levitt, 2004a; Harty, 2005; Alin et al., 2013) and aligning the process of adoption within the assimilation stages (Cooper and Zmud, 1990; Gallivan, 2001). The study suggests that the individual constituent elements which comprise BIM are subject to a process of adoption if they are perceived as novel by the actor. To the best of knowledge, the marriage of the assimilation gap concept with the diffusion behaviour of a systemic, modular innovation is a novel contribution not just to BIM adoption research, but to the wider IS domain.

3. Thirdly, this research has built on attempts in previous BIM adoption studies to provide a critical review of the most common theories and models related to IS-based innovation adoption as applicable to BIM (e.g. Davies and Harty, 2013b;

Bosch-Sijtsema et al., 2017; Ahmed and Kassem, 2018; Dowsett and Harty, 2018; Oesterreich and Teuteberg, 2019, etc.). Whilst appraising BIM as an innovation grounded in an IS-based setting provides nuanced interpretations of the adoption process, current efforts generally ignore the multifaceted nature of BIM and rather approach BIM adoption as a dichotomous decision: either the practitioner or organisation has adopted BIM, or they have not (Petter, DeLone, and Mclean, 2008). Although such theories and models are robust and well-researched within the domain in which they were built, this study demonstrates that the analysis of BIM adoption requires considerations that are over and beyond those captured by these theories and models. The thesis therefore contributes to literature on the adoption of complex, systemic innovations over traditional simple technology applications.

4. Fourthly, the research drew on long-standing debates within the social sciences to inform the inter-level interactions between the micro-level constituents and the macro-level phenomena (Coleman, 1986; Briscoe, Trewhitt, and Hutto, 2011; Raub, Buskens &, and Van Assen, 2011; Tscherning, 2011). Although previous work acknowledges the interaction between these levels and scales of analysis, the sociological connotations are often neglected which can compromise our ability to interpret results effectively. This research also further established the connotations with IS research by drawing on the Multilevel Framework for Technology Adoption (MFTA) to inform theory construction (Tscherning, 2011).

5. Next, this study developed an integrated conceptual framework around adoption and diffusion behaviour at the micro- and macro-levels respectively. Using the MFTA as a guiding framework, the model was constructed by drawing on extant BIM adoption literature and traditional IS theory. The data collection and analysis processes resulted in the refinement of the original model in order to produce a testable framework. The final iteration of the unified BIM Adoption, Assimilation and Use Model for this study is presented in Figure 9.2.

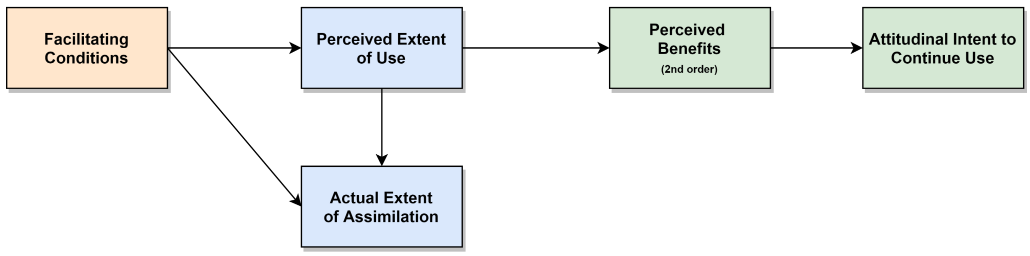


Figure 9.2 Revised BAAUM in response to the hypothesis testing

6. Finally, this work responds to several of the prescriptions identified in the critique of Jeyaraj et al. (2006), and in doing so also extends beyong the so-called *dominant paradigm of IS theory* (Fichman, 2004). Notably, the research focused on the study of outcomes as a dependable variable (Prescription 8), in addition to utilising a construct pertaining to the actual use of an innovation (Prescription 9). Furthermore, the study also employed environmental characteristics when conceptualising the antecedent drivers (Prescription 6). Lastly, the research drew from constructs which had exhibited promising relationships in previous studies, including those identified by Jeyaraj et al. (2006) as "best" or "promising" predictors in individual level research (Prescriptions 1 and 2).

9.2.2 Methodological Contributions

The methodological contributions of the research are as follows:

1. This research has conceptualised and developed two distinct but complementary constructs: Perceived Extent of Use and Actual Extent of Assimilation. The former utilised measures grounded within the UK BIM discourse, such as employing measures striving to capture the BIM maturity Levels as promoted by the Bew-Richards wedge (BIM Industry Working Group, 2011). This included direct reference to the perceived business-as-usual level, in addition to self-reported competency in each of the key standards.

2. The latter, the Actual Extent of Assimilation factor, applied a series of dichotomous measures drawn from previous commercial-based surveys (e.g. NBS, 2020).

However, the application of a raw score in order to capture the Actual Extent of Assimilation construct was considered insufficient as the spacing between scores is not guaranteed to be equidistant, nor can we assume that all items have the same weighting. Therefore, this study employed a unidimensional Item Response Theory (IRT) approach to diagnose the measures and prepare the data for further analysis (Sjitsma, 2004; Kreiner, 2013; Rusch et al., 2017). The application of IRT appears to be novel in the BIM adoption and assimilation setting.

3. Furthermore, the IRT analysis provided methodological insight into its integration with Structural Equation Modelling (SEM) (Lu, Thomas, and Zumbo, 2005; Salzberger, 2011). Instead, a Rasch analysis, which is a form of IRT, was used to overcome the limitations associated with the Classical Test Theory (CTT) approach typically employed within factor analysis. The Rasch analysis was used to calculate the person parameter which served as the factor score for input into the structural model as a single-item construct following the technique pioneered by Salzberger (2011).

4. The application of the IRT-cum-Rasch approach to the analysis of the dichotomous, nominal data has provided an item-driven approach to understanding assimilation as the latent construct. This has practical applications; Rasch analysis is particularly beneficial for developing a series of measures which can appropriately capture a latent trait, irrespective of the person parameter. For this reason, measures developed using such an approach can form an accessible pool of determinants from which to inform future studies. This has practical implications as it is suggested that commercial and industry-based surveys also utilise such a resource to ensure methodological rigour and consistent findings.

9.2.3 Practical Contributions

Finally, the research has provided the following practical contributions:

1. Whilst the UK has been positioned as a leader in BIM diffusion, this study has challenged these perceptions and presented a case for developing a deeper insight

into the efficacy of its diffusion mechanisms. To contextualise the study to sit within a UK setting, the conceptual framework underpinning the BAAUM is derived from a path model built upon the initial UK BIM hypothesis. The measures used to capture the Perceived Extent of Use and Actual Extent of Assimilation constructs are also derived from elements within the BIM discourse (e.g. standards, key documents, Levels, etc.). By grounding the conceptual framework and resultant model within the context of UK BIM governance, the findings have implications for policymakers by presenting a methodology which is inherently aligned to the processes being employed within the UK. This means the findings highlight the inefficacy of elements within the UK's BIM diffusion strategy which are otherwise not apparent in the optimistic appraisals of BIM adoption as promoted by commercial survey efforts.

2. By highlighting the role of assimilation in the adoption process, this study also have implications for practice. This is because practices should consider BIM as a multifaceted system and should therefore assess which elements are most applicable for their own processes. By triggering adoption decisions for individual constituents of BIM rather than the whole system, the adoption process may be more achievable, particularly where upfront cost and investment are significant barriers.

3. The descriptive analysis of all constructs originally specified within the BAAUM has provided empirical evidence that there is an assimilation gap effect at the micro-level. This has practical implications as these findings can be used to better understand and quantify BIM assimilation at a local level. Moreover, the BAAUM, once refined and empirically validated, can be used to develop instruments which assess the efficacy of an individual's assimilation process. This has implications for individual practitioners who may wish to identify limitations in their competencies with regards to BIM adoption and use, or for organisations and thought leaders who wish to establish a 'state of play' of a group of individuals. There are also implications for training and education providers, who may wish to utilise the results to tailor courses and roadmaps to individuals in response to their extent of assimilation.

9.3 RESEARCH LIMITATIONS

As a predominantly exploratory study that employs abductive reasoning and pragmatic philosophical principles, this study comprises the first stage of an iterative process in which the study can continue to be refined and appropriately respond to academic and industrial challenges. Whilst every effort has been made to develop a comprehensive research design, limitations exist within the study. This section discusses these limitations and provides suggestions for further research to respond to these shortcomings.

9.3.1 RESEARCH FOCUS

The development of the theoretical framework for this study was informed by recommendations to draw from the IS domain (e.g. Merschbrock and Erik Munkvold, 2012; Oesterreich and Teuteberg, 2019). The review in Chapter FIVE subsequently focussed on a core set of theoretical models and frameworks within this arena using extant BIM adoption research to drive the narrative. However, other theoretical perspectives have been applied to BIM adoption, such as sociotechnical theory (e.g. Arayici et al., 2011a; Sackey, 2014; Sackey, Tuuli, and Dainty, 2015; Oesterreich and Teuteberg, 2019), activity theory (e.g. Miettinen and Paavola, 2014; Mäki and Kerosuo, 2015; Akintola, Venkatachalam, and Root, 2017), actor-network theory (e.g. Linderoth, 2010; Lindblad, 2019b; Zomer et al., 2020) competitive dynamics perspective (e.g. Hosseini et al., 2018), and Maslow's motivational theory on the hierarchy of needs (Singh and Holmstrom, 2015). Moreover, it is likely that there are theoretical frameworks from other research domains that have not yet been applied or adapted to BIM adoption and assimilation, particularly in areas looking at upskilling, education, and worker-based competency. Therefore, it is recommended that further research is done to appraise these other areas and to capture a wider remit of theoretical perspectives.

This study has also briefly drawn upon research considering Enterprise Resource Planning (ERP) to inform its thesis. Similar to how BIM has been appraised within this work, ERP is also considered by scholars to be a systemic modular innovation grounded in integrated IS-based technologies (e.g. Bajwa, Garcia, and Mooney, 2004; Liu et al., 2011). Therefore, it is recommended that future studies consider aligning BIM adoption, assimilation and utilisation research with approaches taken to understanding ERP. For example, the discussions surrounding the application of traditional IS-based innovation adoption theory to BIM adoption could be extended to assess their application to ERP. As a more established innovation which is applicable to multiple industry contexts, the ERP systems perspective may provide additional insight into theory application and construction in such arenas.

9.3.2 Construct Conceptualisation

This study attempts to measure the Perceived Extent of Use and Actual Extent of Assimilation constructs concerning BIM use by employing measures used in industry-based surveys and studies. Whilst employing this approach provides practical validity to the measures, the methodologies underpinning these sources are often not reported, as critiqued in Chapter TWO. Therefore, it is suggested that future research should seek to further develop the Perceived Extent of Use and Actual Extent of Assimilation constructs by drawing on tested methods, such as Delphi studies, to systematically inform measure construction.

Furthermore, the measure of assimilation was designed to be broad and to capture a wide range of generalised BIM competencies. In reality, individual roles and functions would assimilate BIM modules to varying extents. Whilst the use of dichotomous measures sought to overcome this to some extent, it is recommended that future studies seek to understand the impact of different roles and functions on what is interpreted as general BIM. On the other hand, future research should also consider defining a parsimonious set of measures which captures agnostic skills and knowledge.

9.3.3 Data Collection Methods

The use of a cross-sectional questionnaire survey does not allow for causal inferences to be made as data are collected at a single point of time. Rather, only correlational inferences can be made. For causality to be drawn, a longitudinal study is preferable. However, as discussed in Chapter THREE, the feasibility of a longitudinal approach is compromised when comparing the time and cost restraints with those of cross-sectional methods. Likewise, the ability to capture a large, consistent sample for a longitudinal design is limited, particularly if qualitative techniques are employed. In addition, the perceptions and competencies of individuals are likely to change as they gain more experience over time.

If wielding an appropriate sample size, the dataset could provide powerful results and be applicable for multiple forms of analysis. However, the main limitation of the study lies in the suboptimal sample size collected. Despite efforts to design a robust sampling strategy which considered and utilised multiple data collection procedures, the sampling was limited and the ability to infer the results to the general population is not possible. It is recommended that future BIM adoption research within a generalised industry setting carefully consider the use of quantitative survey methods, particularly when employing nonprobability sampling techniques.

It is also suggested that academia and commercial- or industry-based bodies work together to overcome the limitations associated with each; commercial surveys would benefit from enhanced methodological rigour and academia would benefit from more exposure to a wider pool of industry professionals. Lastly, it is also recommended that government statistics be used as a proxy for determining the representativeness of the achieved sample. Although the current Standard Industrial Classification system does not capture the AECO entirely within a bounded category, the SIC could provide indicative figures for comparison.

9.3.4 Data Analysis Methods

To somewhat navigate the issue of a small sample size, an Exploratory Factor Analysis (EFA) was conducted to achieve dimensionality reduction. Although this resulted in eliminating several elements from the BAAUM, the EFA allowed for the study to continue whilst retaining the core relationships as hypothesised within the model. Furthermore, the PLS-SEM data analysis technique was chosen over the alternative covariance-based SEM (CB-SEM). However, although it is noted in literature that the PLS-SEM approach is more powerful in dealing with smaller samples, a larger sample size is desirable in order to derive more robust conclusions. This is because small samples are more sensitive to data analysis procedures and are inherently less reliable than larger samples (Chin et al., 1998). For this reason, the relationships inferred within this study should be used as a guide when considering next steps of inquiry, rather than represent an absolute state-of-play of industry use and assimilation of BIM. The study has demonstrated that it is however still possible to generate beneficial insights from such a sample size. This is because the exploratory nature and abductive reasoning employed by the research provides a framework against which further studies can be built with the cognisance of these limitations and risks.

It is recommended that future research should seek to undertake a full IRT analysis on all constructs, including those on Likert scales. Whilst the dichotomous Rasch model applied here would not be applicable, a polytomous model using two- or three-parameter IRT models could contribute. This would provide richer insight into item parameters by also estimating the item discrimination factor.

Lastly, the SmartPLS software did not provide a facility to specify the error variance and latent construct variance as calculated in Section 8.2.6. This resulted in the person parameter as calculated from the Rasch analysis being treated as a typical single-item construct in which the regression coefficient is specified as 1.0. Within SmartPLS, this demonstrates that the single determinant and the latent construct are the same measure. Future research seeking to integrate IRT and Rasch analysis procedures with SEM methods should consider this software limitation when developing their research design.

9.4 Suggestions for Future Research

Having acknowledged the limitations of the current study, this section provides directions for future research on the adoption, assimilation and utilisation of BIM. Firstly, further research should first aim to address the practical limitations by following the recommendations set out in the previous section. However, the prevailing rhetoric of this study is one of an exploratory nature, thereby presenting an opportunity to build on these foundations and further develop the narratives developed within this thesis. This section therefore discusses the opportunities for future research.

9.4.1 Research Design: Next Steps

Using pragmatist principles, Chapter THREE described the research design as one of an exploratory sequential nature. Furthermore, the abductive reasoning employed within the study creates a cyclical approach to the research design process in which the results of Phase II do not automatically feed into Phase III as is, but rather can be used to continually revise and eventually validate the research instrument. This provides the opportunity for the research to continuously respond and adapt to the challenges and limitations presented during data collection and analysis, such as employing measures to counter the small sample size.

A revised version of the research design process is presented in Figure 9.3. Compared to the initial diagram presented in Figure 3.2, Figure 9.3 presents a more reactive approach to the process, based on our new-found understanding of the pitfalls and limitations of the research design. As illustrated, there are several potential routes to follow. The first suggests revisiting the initial stages in Phase I which could be structured around a more developed set of questions and themes, either by retaining the focus group interview format or by consulting one-to-one with relevant individuals.

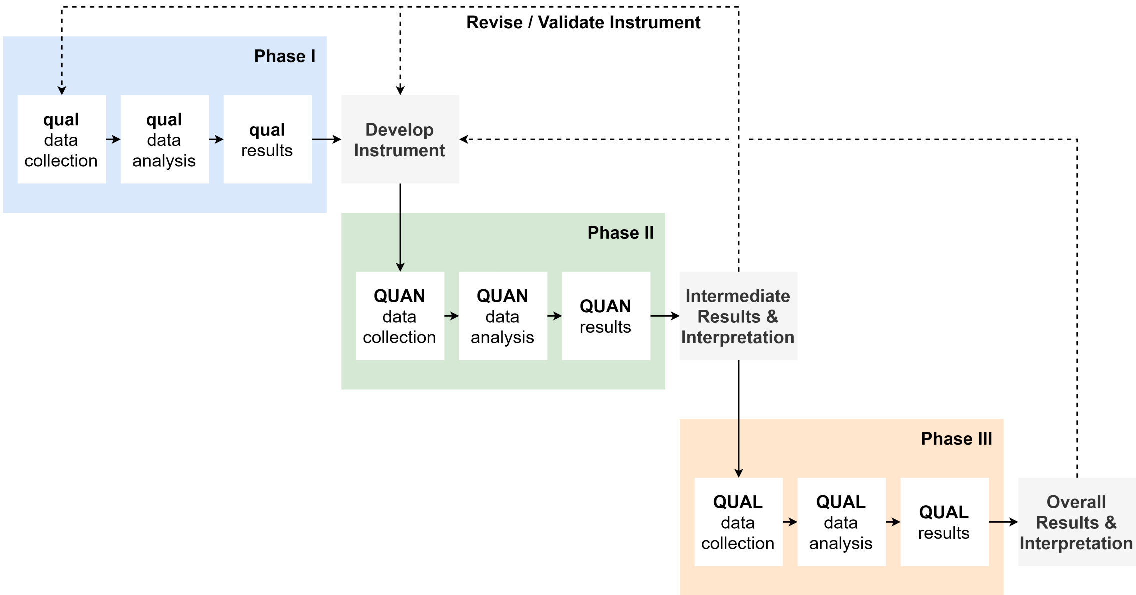


Figure 9.3 Revised research design process, after Figure reffig:Research Design

Alternatively, the instrument could be revised to suit the findings of the present study and the amended BAAUM, and re-distributed to a similar target population. This would enable the relationships within the model to be tested within the new setting, thereby presenting an opportunity to empirically validate the relationships posited here. Alternatively, the original BAAUM and data collection instrument could be tested again but using a defined target population. As briefly discussed in Chapter SEVEN, consideration was given to the use of institute-hosted databases. Although it was impractical to do so within the context of the present research problem, a well-defined sampling and distribution approach using a single, appropriate database which is supported by the relevant institute may provide a larger, more reliable sample. Although the focus on a single institute is unlikely to be representative of the wider industry, such a specialised sample may provide novel insights into the BAAUM's theorised relationships and provide an opportunity to consider insights at a group-level.

It is recommended that there are several revision and validation steps to ensure the instrument is sound and that the BAAUM is appropriately parsimonious. Moreover, Figure 9.3 highlights that instrument validation could proceed through to the Phase III which provides more emphasis on the qualitative techniques to validate the instrument and to explain the measured phenomena. It is recommended that Phase III embraces a more involved qualitative approach than that employed in Phase I in order to provide deeper, contextualised insights. For example, case studies with ethnographical elements may provide a richer understanding of how individuals and organizations approach the issue of upskilling, thereby contextualising the use and assimilation findings assessed using the BAAUM.

However, unlike Figure 3.2, Phase III does not represent the final stage, but rather opens the process up to consider further development based upon the qualitative findings. This is because Phase III should also contribute to and refine the research design by applying practical insight, rather than being relegated to a confirmation exercise only. This is critical when considering the ongoing evolution of the sector and of the corresponding research domain.

Finally, the next steps of research should also consider the provision of recommendations based on the findings of the research. In particular, recommendations should be focused at the policymaking level, looking at both diffusion behaviour and at upskilling practices. Based on the preliminary research presented here, it is suggested that these two areas are consolidated and equal consideration given to both domains. An open dialogue between policymakers and upskilling providers is encouraged to ensure measurement exercises appropriately capture the nuances of BIM adoption.

9.4.2 Potential Routes of Inquiry

In addition to the prescribed research design process, a non-exhaustive list of further routes of inquiry based upon the discussions within this study is provided below:

- Several factors which were supported in literature and by the descriptive analysis were eliminated due to quality issues during the EFA and measurement model assessment stages of the analysis. It is recommended that future research still considers these constructs and to reassess their role in the BAAUM if a larger sample size is achieved. This is because if a sufficient sample size is achieved, dimensionality reduction will not be a necessary step which would result in factors such as Self-Efficacy being retained for further analysis. This exercise should be considered for all untested relationships within the original BAAUM.

- Using the assimilation gap concept as explored in Chapter TWO, it is suggested that future work consider assessing the diffusion of individual BIM modules. It is recommended this work build on existing studies, such as the focus on 4D as provided by Gledson (2016; 2017) or on individual BIM functions, e.g. Gholizadeh et al. (2018).

- A larger sample size would allow different multivariate analyses to be conducted on the data collected. Based on data collected using the instrument developed within the present study, it is recommended that a discriminant analysis is conducted to assess group differences between those who have adopted BIM and those who have not. A suggested high-level research model using the constructs developed in this research is presented in Figure 9.4.

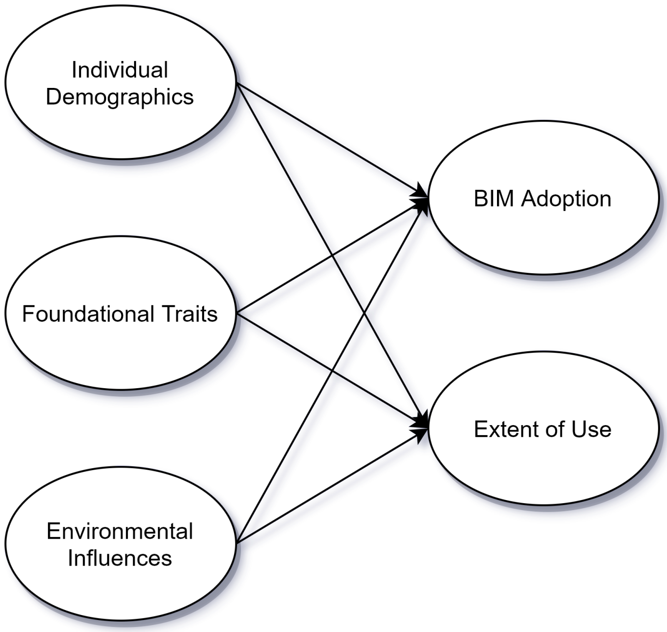


Figure 9.4 Suggested research model for discriminant analysis

- Related to the point above, future research should consider applying core competency elements as interacting moderators or to the present research. For example, the Historical Indicators or Qualifications and Licences collected to assess demographic information could be structured as dummy variables in order to control for group differences. Alternatively, future work should consider supplementing univariate statistics such as those provided in Chapter SEVEN with bivariate statistics to analyse potential relationships between such variables and the model constructs.

- Generally speaking, research should consider how macro-level quantitative research is conducted within a heterogeneous sector. Efforts should be made to develop guidance and best practice surrounding the application of social science methods in the AECO context.

9.5 Departing Remarks

This research set out to explore the role of micro-level factors on achieving an effective macro-level diffusion of BIM in the UK. BIM is presenting a new and fascinating sector-wide paradigm shift which is not only challenging industry, but also our industry's politics and education and training model. Having led the charge on the publication of BIM standards in the 2010s and now feeding into and sculpting the standards on a global stage, the UK has been seen as a digital leader in the AECO space. However, as the UK starts to move towards digital twins and away from the BIM Levels, we need to be sure we don't run the risk of slipping right back into old Eganian habits with a "best practice in small pockets" reality. This is because although the ISO standards are similar in core principles to the Level 2 suite of standards, industry will still require a shift in process and terminology and thus adopters will have to adapt again, threatening a further lag in whole-BIM assimilation. Ultimately, as the industry quite rightly pushes forward with its overarching digital agenda and even at times adjusts its course, we need to be able to support and encourage the many people within it to be able to join us on this journey.

This research therefore calls for caution on overoptimistic appraisals of BIM diffusion, particularly those emanating from commercial surveys. Moreover, the introduction of BIM presents us with an opportunity to redefine our understanding of systemic innovations by moving away from a dichotomous approach to adoption and use behaviour, and instead embracing the connotations of assimilation at the micro- and macro-levels. Using this multilevel perspective as the framework, this study provides a departure point for future research to develop this assimilation gap concept, and calls on both micro- and macro-scholars to meet in the middle and bridge the gap.

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List of Appendices

Appendix A

A.1. BIM-related Standards in the UK

Part	Year	Title	Notes
BS 1192			
+A2	*2007 + 2016*	*Collaborative production of architectural, engineering and construction information. Code of practice*	Part of the original Level 2 suite of standards, but has now been superseded by BS EN ISO 19650-1:2018 and -2:2018 under the UK BIM Framework.
4	2014	Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice	Part of the original Level 2 suite of standards, but to be superseded by BS EN ISO 19650-4 under the UK BIM Framework.
PAS 1192			
2	*2013*	*Specification for information management for the capital/delivery phase of construction projects using building information modelling (CAPEX)*	Part of the original Level 2 suite of standards, but has now been superseded by BS EN ISO 19650-1:2018 and -2:2018 as part of the UK BIM Framework.
3	*2014*	*Specification for information management for the operational phase of assets using building information modelling (OPEX)*	Part of the original Level 2 suite of standards, but has now been superseded by BS EN ISO 19650-3:2020 as part of the UK BIM Framework.
5	*2015*	*Specification for security-minded building information modelling, digital built environments and smart asset management*	Part of the original Level 2 suite of standards, but has now been superseded by BS EN ISO 19650-5:2020 as part of the UK BIM Framework.
6	2018	Specification for collaborative sharing and use of structured Health and Safety information using BIM.	Part of the original Level 2 suite of standards. At the time of writing, no comment has been made on the supercession of PAS 1192-6 and is still considered a current standard as part of the UK BIM Framework.
BS EN ISO 19650			
0	2018	Transition guidance to BS EN ISO 19650.	National foreword to the UK's implementation of BS EN ISO 19650.

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Table A.1 – *Continued from previous page*

Part	Year	Title	Notes
1	2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling – Information management using building information modelling: Concepts and principles	Part of the UK BIM Framework suite of standards.
2	2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling – Information management using building information modelling: Delivery phase of the assets	Part of the UK BIM Framework suite of standards.
3	2020	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling - Part 3: Operational phase of the asset	Part of the UK BIM Framework suite of standards.
4	2022	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling - Part 4: Information Exchange	Publication expected in 2022 and will form part of the UK BIM Framework suite of standards.
5	2020	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling - Part 5: Security-minded approach to information management	Part of the UK BIM Framework suite of standards.
BS 7000			
4	2013	Design management systems. Guide to managing design in construction	Supporting standard.
PAS 91			
+A1	2013 + 2017	Construction prequalification questionnaires (PQQ)	Supporting standard. Aligned to the Government Construction Strategy. BIM forms one of the optional modules within the questionnaire.
BS 8536			

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Table A.1 – *Continued from previous page*

Part	Year	Title	Notes
1	2015	Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure)	Both standards are derived from Government Soft Landings and are part of the original Level 2 suite of standards. At the time of writing, no comment has been made on the internationalisation of BS 8536-1 or -2. They are still considered a current standard under the UK BIM Framework.
2	2016	Briefing for design and construction. Code of practice for asset management (Linear and geographical infrastructure)	
BS 8541			
1	2012	Library objects for architecture, engineering and construction. Identification and classification. Code of practice	Both standards are part of the original Level 2 suite of standards. At the time of writing, no comment has been made on the supercession of BS 8541-1 or -2. They are still considered a current standard under the UK BIM Framework
2	2011	Library objects for architecture, engineering and construction. Recommended 2D symbols of building elements for use in building information modelling	
3	2012	Library objects for architecture, engineering and construction. Shape and measurement. Code of practice	Supporting standard.
4	2012	Library objects for architecture, engineering and construction. Attributes for specification and assessment. Code of practice	Supporting standard.
5	2015	Library objects for architecture, engineering and construction. Assemblies. Code of practice	Supporting standard.
6	2015	Library objects for architecture, engineering and construction. Product and facility declarations. Code of practice	Supporting standard.
BS EN ISO 12006			
2	2020	Building construction. Organization of information about construction works. Framework for classification	Supporting standard.
3	2016	Building construction. Organization of information about construction works. Framework for object-oriented information	Supporting standard.
BS 29481			

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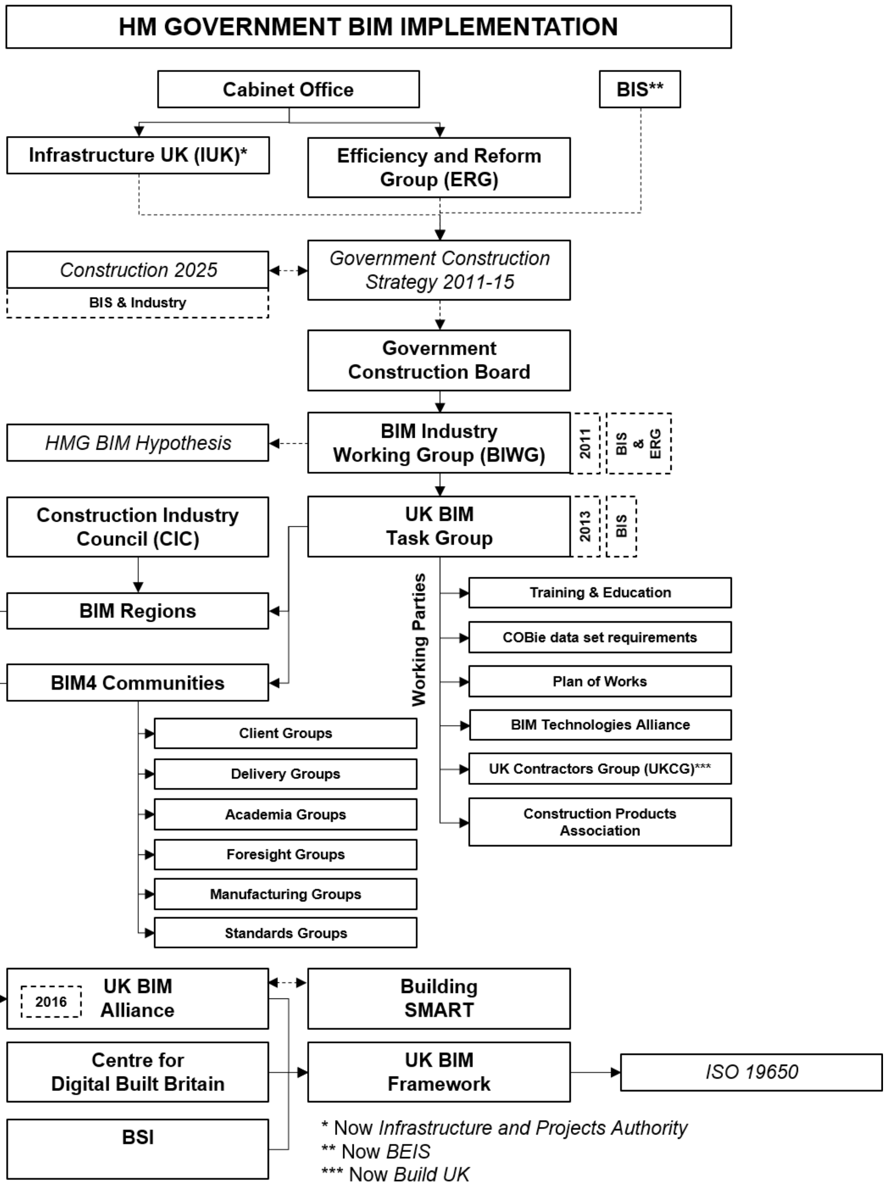
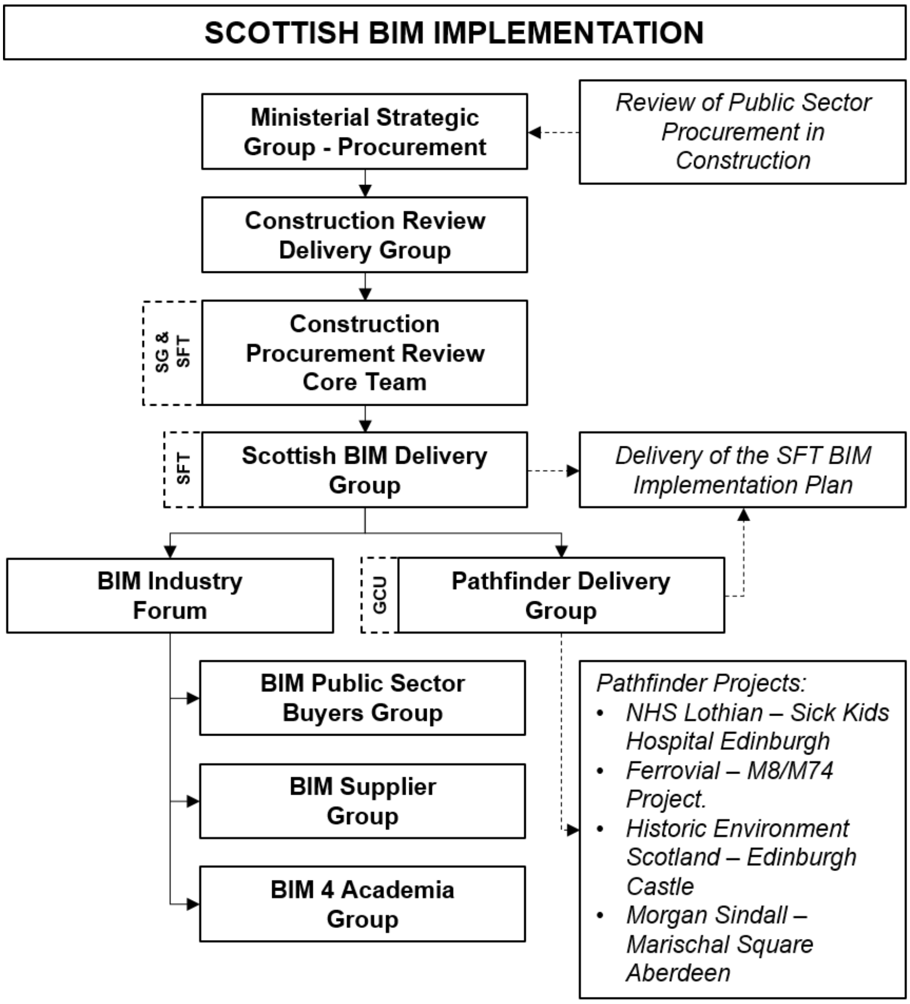
Table A.1 – *Continued from previous page*

Part	Year	Title	Notes
1	2016	Building information models. Information delivery manual. Methodology and format	Supporting standard.
BS EN ISO 16739			
1	2018	Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema	Supporting standard.

A.2. UK BIM Governance and Timeline



A.3. Scottish BIM Governance and Timeline



Appendix B

B.1. Theory and methods used in BIM Adoption Studies

The following table (next page) provides an overview of each of the studies included in Table 5.1. The information has been extracted from the relevant paper where possible. The table sets out the name of the study and the country of focus. It also identifies the level of analysis, in accordance with the terminology set out in Section 2.1.3. This appendix expands on the information provided in Table 5.1 by explaining how the identified theories have been used in more detail. Data collection and analysis methods are also outlined and presented using the notation devised by Creswell and Plano Clark (2007).

Study	Country	Level	Theory	Data Collection Methods			Data Analysis Methods
				QL/QT	Item Validation	Technique	
Acquah & Oteng (2018)	Ghana	Micro	TAM	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 125 valid responses using purposive sampling and in-person distribution.	**Hypothesis testing** using Correlation Analysis (Pearson) and Multiple Regression.
Addy, Adinyara & Ayarkwa (2018)	Ghana	Micro	UTAUT2	qual ⟶ QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 72 valid responses using convenience sampling, preceded by an unstructured interview to assess respondent knowledge and to provide prerequisite information to the participant.	**Exploratory Factor Analysis**, using Principal Component Analysis with Varimax Rotation. **Hypothesis testing** using Multiple Hierarchical Regression.
Ahuja et al. (2016)	India	Meso (Org)	Adapted TOE, based on constructs identified in literature.	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 184 valid responses distributed via email.	**Hypothesis testing** using Partial Least Squares.
Ayinla & Adamu (2018)	UK/Global	Meso (Org)	Integration of DOI, the Bew-Richards Maturity Model, and the Singh-Holmstrom technology adoption model.	QUAN ⟶ QUAL	*Unspecified.*	**Questionnaire Survey** with 241 valid responses using web-based distribution. **Semi-Structured Interview** with 9 participants using purposive sampling and was conducted using the telephone.	**Descriptive Analysis** using cross-tabulation methods in SPSS. **Hypothesis testing** using the Pearson x^2 test in SPSS. **Thematic Analysis** using NVIVO. The interviews were used to validate and refine the conceptual model.
Bosch-Sijtsema et al. (2017)	Sweden	Meso (Org)	Informed by TPB and TOE	QUAL + QUAN	Instrument constructed from interview findings and literature review.	**Interview** with 7 professionals across 3 job levels of mid-sized contractor firms. **Quantitative Survey** with 32 valid responses (out of 104) aimed at CEOs and conducted over the telephone.	**Descriptive Analysis**, and Pearson Correlation Analysis (not for hypothesis testing).

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Table B.1 – *Continued from previous page*

Study	Country	Level	Theory	Data Collection Methods			Data Analysis Methods
				QL/QT	Item Validation	Technique	
Cao et al. (2014a)	China	Meso (Org)	Adapted InT	qual ⟶ QUAN	Instrument constructed from literature review, project observation, and semi-structured interviews. Pilot Study with 23 participants tested validity of related constructs.	**Questionnaire Survey** with 92 project-specific responses, distributed using email, in-person visits, and online.	**Hypothesis testing** using Partial Least Squares Structural Equation Modelling, with a bootstrapping procedure (5,000 resamples).
Cao et al. (2016)	China	Meso (Org)	Integration of DOI and InT	qual ⟶ QUAN	Literature review and semi-structured interviews with 4 industry professionals. **Questionnaire Survey** with 21 respondents conducted as a pretest.	**Questionnaire Survey** with 81 valid responses conducted using in-person visits and online distribution.	**Confirmatory Factor Analysis**, Descriptive Analysis and Hierarchical Regression.
Davies & Harty (2013a)	UK	Micro	TAM with UTAUT & DOI constructs	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 762 valid responses, distributed within a single, large organisation via email with a prize draw as incentive.	**Exploratory Factor Analysis**, with Principal Component Analysis with Varimax Rotation.
Dowsett & Harty (2018)	UK	Meso (Pro)	ISSM	QUAL	*Unspecified*	**Case Study Approach** with 2 projects, using **Semi-Structured Interviews** with 15 professionals (Case Study 1) and 12 professionals (Case Study 2).	**Interpretive Analysis**, using narrative construction and thematic mapping based on the ISSM constructs. Case Study 2 was used to validate the findings of Case Study 1.
Gholizadeh et al. (2018)	US	Macro	DOI (with a focus on diffusion modelling)	QUAN	Measures adapted from previously validated instruments. New measures (specifically those relating to BIM functions) have been derived from literature.	**Questionnaire Survey** with 118 valid responses using email distribution via publicly accessible member lists and in-person within a conference setting.	**Parameter Estimates** using Ordinary Least Squares method, and **Diffusion Modelling** using Internal (Logistic), External, Bass, and Gompertz Models.

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Table B.1 – *Continued from previous page*

Study	Country	Level	Theory	Data Collection Methods			Data Analysis Methods
				QL/QT	Item Validation	Technique	
Gledson & Greenwood (2017)	UK	Macro	DOI	QUAN	*Unspecified.*	**Questionnaire Survey** with 97 valid responses, using purposive sampling and online distribution.	**Descriptive Analysis** and **Hypothesis testing** using Inferential Analysis and x^2 test. Relative Importance Index was calculated for the Relative Advantage construct.
Gurevich et al. (2017)	UK	Meso (Org)	"BIM Adoption Impact Map", informed by TAM and TTF	QUAL	Measures drawn from literature findings, and authors' experience.	**Case Study Approach** with 5 public facility agencies, using face-to-face **Structured Interviews** with each agency's BIM adoption team.	**Systematic Analysis** using the developed "BIM Adoption Impact Map".
Hilal et al. (2019)	Australia	Macro	Integration of TTF and UTAUT	QUAL	N/A	**Literature Appraisal**. No empirical research was conducted.	N/A.
Hosseini et al. (2016)	Australia	Meso (Org)	DOI	QUAN	Measures adapted from previously validated instruments and sent to project managers for pretesting.	**Questionnaire Survey** with 149 valid responses out of 1365 using postal and email distribution.	**Hypothesis testing** using Partial Least Squares Structural Equation Modelling.
Howard et al. (2017)	UK	Micro	Adapted UTAUT	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 84 valid responses using online distribution.	**Hypothesis testing** using Covariance-based Structural Equation Modelling.
Juan et al. (2017)	Taiwan	Meso (Org)	TAM, integrated with Knowledge Management Systems (KMS) and Balanced Scorecard (BSC)	QUAN	Unspecified.	**Questionnaire Survey** with 224 valid responses using in-person distribution in a conference environment.	**Exploratory Factor Analysis** with an unspecified rotation method. **Predictive model development**, using the Artificial Neural Network (ANN) method.

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Table B.1 – *Continued from previous page*

Study	Country	Level	Theory	Data Collection Methods			Data Analysis Methods
				QL/QT	Item Validation	Technique	
Kim et al. (2016)	Korea	Micro	Integration of DOI and TAM constructs	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 303 valid responses, conducted in-person and via email distribution.	**Confirmatory Factor Analysis** and **Hypothesis testing** using Structural Equation Modelling.
Lee & Yu (2016)	Korea & US	Micro	Integration of DOI and TAM	qual ⟶ QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 164 valid responses.	**Factor Analysis** using Exploratory Factor Analysis, and **hypothesis testing** using Structural Equation Modelling.
Lee & Yu (2017)	Korea	Micro	Integration of ISSM and TAM	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 164 valid responses	Discriminant Analysis between groups.
Lee et al. (2015)	Korea	Micro	"BIM Acceptance Model", based on TAM	qual ⟶ QUAN	Content validity assessed through face-to-face **Interviews** with experts.	**Questionnaire Survey** with 114 valid responses from experienced BIM users using email distribution.	**Factor Analysis** using Exploratory Factor Analysis, and **hypothesis testing** using Structural Equation Modelling.
Merschbrock & Nordahl-Rolfsen (2016)	Norway	Micro	TAM	QUAL	N/A	**Case Study approach** focusing on 1 project and using **Semi-Structured Interviews** with 8 professionals involved on the project.	**Content Analysis** using the TAM constructs.
Qin et al. (2020)	China		TAM and TOE	QUAN	A standardised question format using interval numbers was employed to assess respondent judgement.	**Questionnaire Survey** with 120 valid responses using online distribution.	Emergent model development using the Decision Making Trial and Evaluation Laboratory (DEMATEL) technique. Factors were analysed for their influencing degree, influenced degree, centrality degree, and causal degree.

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Table B.1 – *Continued from previous page*

Study	Country	Level	Theory	Data Collection Methods			Data Analysis Methods
				QL/QT	Item Validation	Technique	
Samuelson & Björk (2013)	Sweden	Meso (Org)	UTAUT, combined with	quan $\longrightarrow$ QUAL	N/A	**Secondary Research** using results from a previous **Questionnaire Survey** and **Interview Study**. The interview involved 11 participants from 11 organisations.	**Interpretive Analysis**, using the devised analytical framework.
Son et al. (2015)	Korea	Meso (Org)	Extension of TAM	QUAN	Measures adapted from previously validated instruments.	**Questionnaire Survey** with 162 valid responses using face-to-face interviews.	**Confirmatory Factor Analysis** and **Hypothesis testing** using Structural Equation Modelling.
Song et al. (2017)	China	Macro	Adaptation of ISSM	qual *longrightarrow* QUAN	Two rounds of **Semi-Structured Interviews** (1st with 5 graduates, 2nd with 7 BIM experts) followed by a Pilot Study. Measures also adapted from previously validated instruments.	**Questionnaire Survey** (113 valid responses) distributed by individual visits, email, and online.	**Hypothesis Testing**: Partial Least Squares Structural Equation Modelling - bootstrapping procedure with 5,000 resamples.
Wang et al. (2016)	China	Macro	Extension of TOE	QUAL	N/A	**Literature Appraisal**. No empirical research was conducted.	N/A.
Wang & Song (2017)	China	Micro	"Conceptual Model of BIM User Satisfaction"	qual $\longrightarrow$ QUAN	**Semi-Structured Interviews** with 7 experienced BIM experts.	**Questionnaire Survey** with 118 valid responses and distributed by in-person visits, email, and online means.	**Hypothesis testing** with Partial Least Squares Structural Equation Modelling, with a bootstrapping procedure (5,000 resamples).
Xu et al. (2014)	China	Macro	Integration of DOI and TAM	qual $\longrightarrow$ QUAN	**Semi-Structured Interviews** with 10 participants (executive vice presidents and project managers).	**Questionnaire Survey** with 98 valid responses, distributed via post and email, in addition to face-to-face. 18 organisations were identified and interviewed for applicability prior to questionnaire distribution.	**Hypothesis testing** using Pearson Correlation Analysis and Stepwise Multiple Regression Analysis.

Appendix C

C.1. Research Ethics Approval Application Form

SEBE RESEARCH INTEGRITY PROCEDURE
ETHICS APPROVAL FORM FOR STUDENT USE

Please complete sections 1 and 2 and sign in section 3, confirming whether you are self-certifying (in which case simply retain a copy of this form with your research materials) or referring the matter to the school academic lead on Research Integrity.

Section 1 – Research details	
Student name and number	Melanie Robinson (40058196)
Supervisor	Prof John Currie
Module leader	
Module number and name	PhD Research

Title of project
Exploring microlevel competency barriers to an effective macro-diffusion of BIM in the UK

Aim of research

To identify microlevel competency factors and their relationship with the effective implementation of Building Information Modelling (BIM) within project-based construction organisations.

Details of the research methods to be used. Please consider all of the following in your response:

a. how the data will be collected (please outline all methods e.g. questionnaires/focus groups/internet searches/literature searches/interviews/observation)

b. data collection tools to be used

c. where the data will be gathered (e.g. in the classroom/on the street/telephone/on-line)

d. who will undertake the data collection if not the lead researcher detailed in section 1 (list all involved and identify each as staff/student)

e. how the data sample will be selected (e.g. random/cluster/sequential/network sampling)

f. the criterion for an entity to be included in the sample

g. how research subjects will be invited to take part (e.g. letter/email/asked in lecture)

h. how the validity and reliability of the findings will be tested

i. if applicable, please attach a copy of the questionnaire/interview questions (for student researchers, please include notification of approval of the questionnaire from your supervisor)

Approved Oct 2016 p1 of 4

Who/what will be the research subjects in the research? a. Staff/Students of Edinburgh Napier (please give details) b. Vulnerable individuals (please give details e.g. school children, elderly, disabled) c. All other research subjects (please give details). *Professional individuals from across the UK construction industry will be invited to participate in an online questionnaire survey hosted on the QuestionPro website.*

Section 2 – Research Subject Details
Will participants be free NOT to take part if they choose? *Yes*
Explain how informed consent will be achieved. *A tickbox within the introduction of the questionnaire survey will be provided for the participant to state their informed consent. The introduction will also outline the research project and state the conditions of consent, including the intent of use of collected data and participant confidentiality.*
If you plan to use assumed consent rather than informed consent please outline why this is necessary. *N/A*
Will any individual be identifiable in the findings? *Yes, a voluntary option to provide an email address will be provided at the end of the questionnaire survey in order for potential follow-up after findings have been processed.*
How will the findings be disseminated? *The findings will likely be published in journal articles and in the final copy of the PhD thesis.*
Is there any possibility of any harm (social, psychological, professional, economic, etc.) to participants who take part or do not take part? If so, give details of the potential harm and the mitigation strategies you have adopted. *No. All responses will be anonymised and results will only be reported on in an aggregate form, ensuring individual responses cannot be identified.*
How / where will data be stored? Who will have access to it? Will it be secure? How long will the data be kept? What will be done with the data at the end of the project? *The data will be collected and stored on the password-protected QuestionPro platform, which provides stringent security measures and ensured participant anonymity. Only the applicant (Melanie Robinson) will have access to raw data on the site, which will also be downloaded to .xls format for analysis purposes. This will also be treated with the highest*

Approved Oct 2016 p2 of 4

confidentiality and will be stored on the applicant's personal hard drive which is only accessible by themselves. *At the end of the PhD project, it is likely the data could be used in a future study by the applicant only. This means data will continue to be stored in a secure location for an indefinite period. This will also be outlined for the purposes of attaining informed consent.*
If payment or reward will be made to participants please justify that the amount and type are appropriate. *N/A*
Any other information in support of your application.

Section 3 – Self-certification (to be signed by both student and module leader or dissertation supervisor)		
Delete as appropriate: I confirm that I have completed the self-certification checklist and have not identified any ethical issues requiring approval.		
	Student	Module leader or dissertation supervisor
Signature		
Name		
Date		

If you have self-certified that best practice has been followed and no ethical issues have been identified, please sign the form and retain with your research materials.

If you need to refer the matter to the school lead on Research Integrity, please sign and email to Dr Jason Monios: j.monios@napier.ac.uk. In most cases Jason will be able to provide guidance and approve the research, but in some cases he may need to take the matter to the next meeting of the school Research and Innovation Committee. Exceptionally, the matter may be referred to the University Research Integrity Committee.

Approved Oct 2016 p4 of 4

C.2. Participant Consent Approval Form

Edinburgh Napier University Research Consent Form

Exploring microlevel competency barriers to an effective macro-diffusion of BIM in the UK

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of BIM adoption to be conducted by Melanie Robinson, who is a postgraduate research student at Edinburgh Napier University.
2. The broad goal of this research study is to explore the influencing factors on the perceived rate of national BIM adoption. Specifically, I have been asked to participate in a focus group activity, which should take no longer than **1 hour** to complete.
3. I have been told that my responses will be anonymised. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.
4. I also understand that if at any time during the focus group session I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it without negative consequences. However, after data has been anonymised or after publication of results it will not be possible for my data to be removed as it would be untraceable at this point.
5. In addition, should I not wish to answer any particular question or questions, I am free to decline.
6. I have been given the opportunity to ask questions regarding the focus group procedure and my questions have been answered to my satisfaction.
7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

Participant's Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

Researcher's Signature Date

C.3. Participant Information Sheet

Edinburgh Napier UNIVERSITY

Institute for Sustainable Construction

PARTICIPANT INFORMATION SHEET

PhD Study: Exploring microlevel competency barriers to an effective macro-diffusion of BIM in the UK

You are being invited to participate in a focus group study for the purposes of gathering data as part of a wider piece of doctoral research. This information sheet provides an outline of the project and the procedures involved in the present study, including what will happen with the information you provide.

Before you decide whether to take part we would like you to understand why the research is being done and what it would involve for you. Please take a few moments to read the following information carefully and take time to decide whether you wish to take part. If you would like more information or have any questions, please contact the research team. Contact details are provided at the end of this document.

1. **What is the purpose of the study?**

   The purpose of the study is to explore the role of a practitioner's level of competency on the wider diffusion of Building Information Modelling (BIM) at a national level. Your experiences and opinions will help us to identify where weaknesses lie within the current industry upskilling model and will help shape further data collection activities within the PhD methodology.

2. **Why have I been chosen?**

   You have been chosen as a key stakeholder for BIM implementation in Scotland's Architecture, Engineering, Construction, and Operations sector. The research aims to provide a multilevel perspective on competency and upskilling within the sector. The researchers are therefore interested in hearing from:

   - **Policymakers**, or leads in national BIM diffusion
   - **Upskilling Providers**, e.g. those who provide education and/or training
   - **BIM Practitioners**

   You will be asked which role you feel describes your position the best. The focus group aims to comprise a mix of 6 to 8 people from various backgrounds.

3. **Do I have to take part?**

   No. Participation is entirely voluntary, and you maintain the right to withdraw and to discontinue your participation at any time without explanation. Your responses will be discarded in this instance. You can request for your data to be withdrawn until publication of the data without giving a reason and without prejudice. For more information on when the data will be published, please contact the research team. Please note: publication in a journal article may precede the publication of the doctoral thesis.

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4. What will my involvement require?

If you would like to be involved, please email the primary investigator, **Melanie Robinson (m.robinson@napier.ac.uk).** Melanie will then contact you to arrange a convenient time, date, and location for the focus group. If you agree to take part, we will then ask you to sign a consent form before the focus group session starts. You will be given this information sheet to keep and a copy of your signed consent form for your records. The study will last **approximately 1 hour**.

The focus group will be structured around a series of exploratory, open-ended questions which will be audio-recorded. You will be asked questions about your general experiences and views on current upskilling processes and the perceived rate of national BIM diffusion. Conversations between participants are encouraged.

5. Will you pay my expenses?

Unfortunately, we are unable to pay you for your time and travel. However, the option to participate via video conference call will be made available.

6. Are there any risks or disadvantages of taking part?

There are no identifiable risks or disadvantages associated with undertaking this study. We do not plan to cover any sensitive issues and your responses will be treated with strict confidentiality (refer to Q9).

7. What are the benefits of my involvement?

We cannot promise that taking part will benefit you directly. However, your involvement will help us understand how the role of competency is situated within the national BIM mandate and within the current industry upskilling model. The results may be used to structure future competency assessments and upskilling policy, thus providing wider societal benefits.

8. How will information I provide be recorded, stored and protected?

A voice recorder will be used to collect your responses. The recordings, any associated raw data (e.g. notes recorded by the researcher and written transcriptions), and processed data will be stored in the researcher's personal data area, which is an Edinburgh Napier University approved network system and is regularly backed up. Non-digital data will be digitised, and physical data will be suitably destroyed using confidential waste procedures Under Edinburgh Napier University's Research Data Management Policy, data will be retained for 10 years after project completion.

9. How will the results be used?

The data will be analysed using qualitative techniques and will be presented within the final PhD thesis. The thesis is published and kept within the Edinburgh Napier University library and within their online repository. Research findings may also be submitted for publication in research journals or presented at a conference. However, results will be presented in an anonymised, coded form and no individual or organisation will be identifiable in line with data protection guidelines. Any personal details provided will be treated with the strictest confidentiality and will be accessible by the primary researcher and their supervisory team only.

10. Who has reviewed this study?

This research complies with the requirements stipulated by Edinburgh Napier University's Code of Practice for Research Integrity. The study has been approved according to the procedures set out in the University's School of Engineering and the Built Environment ethics approval process.

11. What if I have an enquiry?

This document is yours to keep for future reference. Should you require any further information on the procedures involved, please feel free to contact the research team using the details provided below.

Name	Role	Telephone	Email
Melanie Robinson	*PhD Candidate*	[redacted]	m.robinson@napier.ac.uk
Prof John Currie	*Director of Studies*		j.currie@napier.ac.uk
Dr Andrew Brown	*Supervisor*		a.brown3@napier.ac.uk

Please contact Prof John Currie if you have any complaints about this research.

You can access information regarding Edinburgh Napier University's Research Data Management Policy and Data Protection Policy Statement by using the contact details above.

Thank you for taking the time to read this Participant Information Sheet.

C.4. Focus Group Agenda

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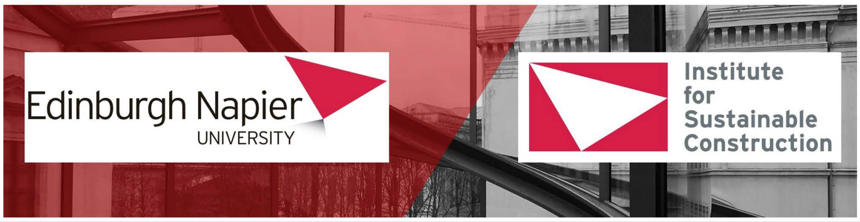
FOCUS GROUP AGENDA

PhD Study: Exploring micro-level competency barriers to an effective macro-diffusion of BIM in the UK

1. **Introduction to the Research** (5mins)
   a. Welcome
   b. Overview of the Topic
   c. Aim of the Focus Group
   d. Focus Group Procedures
2. **Introduction to the Participants** (5mins)
   a. Brief Introduction and Background
   b. *How experienced are you with BIM?*
   c. *What experiences have you personally had with BIM upskilling activities? (e.g. do you deliver or receive training, or both)*
3. **THEME 1: (Macro-Level) BIM Adoption Rate Assessments** (10mins)
   a. *What do you think about the need to measure the rate of BIM adoption at an industry level?*
4. **THEME 2: (Micro-Level) Individual Adoption/Use** (10mins)
   a. *What do you think are the factors that are most important for a person to consider themselves to have successfully adopted BIM?*
5. **THEME 3: (Macro-Level) Upskilling Provision** (10mins)
   a. *What do you think of the current BIM upskilling (education & training) provision for industry practitioners at the moment?*
6. **THEME 4: (Micro-Level) BIM Competency** (10mins)
   a. *What does the term "BIM Competency" mean to you?*
7. **Debriefing and Summary** (5mins)
   a. Summary of Discussion
   b. *Finally, is there anything connected with the relationship between BIM adoption and upskilling which has not been discussed that you feel strongly about and would like to bring up now?*

D.1. Questionnaire Survey Participant Information Page



BIMplementation - Where are you in the UK's BIM journey?

Hello! At Edinburgh Napier University, we are exploring the impact of individual understanding on the adoption of Building Information Modelling (BIM) as part of ongoing doctoral research.

You will have received this questionnaire as you are deemed to be a member of the UK's Architecture, Engineering, Construction, and Operation (AECO) sector. Therefore, you are warmly invited to participate in this survey.

Please note: You don't have to have adopted BIM to take part!

It will take approximately ~15 minutes to complete the questionnaire, which is split into 2 sections:

- Section 1: Your current state of implementation and perception of BIM
- Section 2: Questions about you and your organisation

Your participation in this study is completely voluntary and the responses will be strictly confidential. The information gathered will be coded and stored safely. Results will only be reported in the aggregate form and will therefore not identify individual responses. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point.

Should you have any questions at any time about the survey or the procedures involved, you can contact the primary researcher, Melanie Robinson, using the details below:

- Phone: [redacted]
- Email: m.robinson@napier.ac.uk

Your time and support is greatly appreciated. We value your honest and detailed responses.

If you are happy with the terms, please start with the survey now by ticking the box and clicking on the Continue button below.

☐ I agree to participate in this survey

* Had you personally heard of Building Information Modelling (BIM) prior to this study?

○ Yes

○ No

BIMplementation QuestionPro

D.2. Questionnaire Survey

* **Please specify where in the UK you currently conduct work.**

Select all that apply.

- ☐ England
- ☐ Scotland
- ☐ Wales
- ☐ Northern Ireland
- ☐ None of the above

*

Decisions made at the Strategic Level refer to decisions made by top management for the organisation.

With this definition in mind, do you consider your organisation to have adopted BIM at the strategic level?

- ◯ Yes
- ◯ No

Does your organisation require you to use BIM?

- ◯ Yes, it is a mandated requirement.
- ◯ No, individual adoption is completely voluntary.

Has your organisation undergone any form of BIM-specific third party certification/accreditation?

- ◯ Yes
- ◯ No
- ◯ Unsure

* **Do you consider yourself to presently use or work with BIM?**

- ◯ Yes, I consider myself to currently use or work with BIM.
- ◯ I do not consider myself to have adopted BIM yet, but I intend to adopt it in the future.
- ◯ I do not consider myself to have adopted BIM and I have no intentions to adopt it.

BIMplementation QuestionPro

How strongly do you agree or disagree with the following statements?

My co-workers think that I should use BIM.

Strongly Disagree

Generally speaking, I respect and put in practice my co-workers' decisions.

Strongly Disagree

My boss thinks I should use BIM.

Strongly Disagree

Generally speaking, I accept and carry out my boss's decision even though it is different from mine.

Strongly Disagree

Senior management thinks I should use BIM.

Strongly Disagree

Generally speaking, I try to follow senior management's policy and intention.

Strongly Disagree

BIMplementation QuestionPro

Please indicate the extent to which...

...the government's promotion of BIM influences you to use it.

Very Low

...competitive conditions influences you to use BIM.

Very Low

...clients want you to use BIM.

Very Low

BIMplementation

QuestionPro

How strongly do you agree or disagree with the following statements?

I have the resources necessary to use BIM.

Strongly Disagree

I have the knowledge and skill necessary to use BIM.

Strongly Disagree

BIM tools and processes are not compatible with the tools and processes I use.

Strongly Disagree

A specific person (or group) is available for assistance with difficulties.

Strongly Disagree

BIMplementation

QuestionPro

How strongly do you agree or disagree with the following statements:

Top Management...

...actively engages in selecting the vendor for BIM tools and consulting firm

Strongly Disagree

...actively engages in recruiting the personnel needed for implementing and operating BIM.

Strongly Disagree

...is much concerned with the performance of BIM.

Strongly Disagree

...makes an effort to provide stable and sufficient funding for BIM implementation and operation.

Strongly Disagree

...emphasises managing and controlling the processes of BIM and operation effectively.

Strongly Disagree

* Are you aware of the efficiency targets for the built environment as set by the UK Government in its Construction 2025 Strategy?

- ◯ Yes
- ◯ No

BIMplementation QuestionPro

* The UK Government introduced BIM in the Government Construction Strategy 2011 and subsequently described there being different levels of BIM maturity.

Are you familiar with the Government Construction Strategy 2011?

- ○ Yes
- ○ No

*** Are you aware of the UK Government's commitment to BIM as described by these different levels?**

- ○ Yes
- ○ No

*** As you identified that you are based in or involved with projects in Scotland, are you also aware of the Scottish Government's commitment to BIM as described by these different levels?**

- ○ Yes
- ○ No

*** Are you aware of the Soft Landings procedures?**

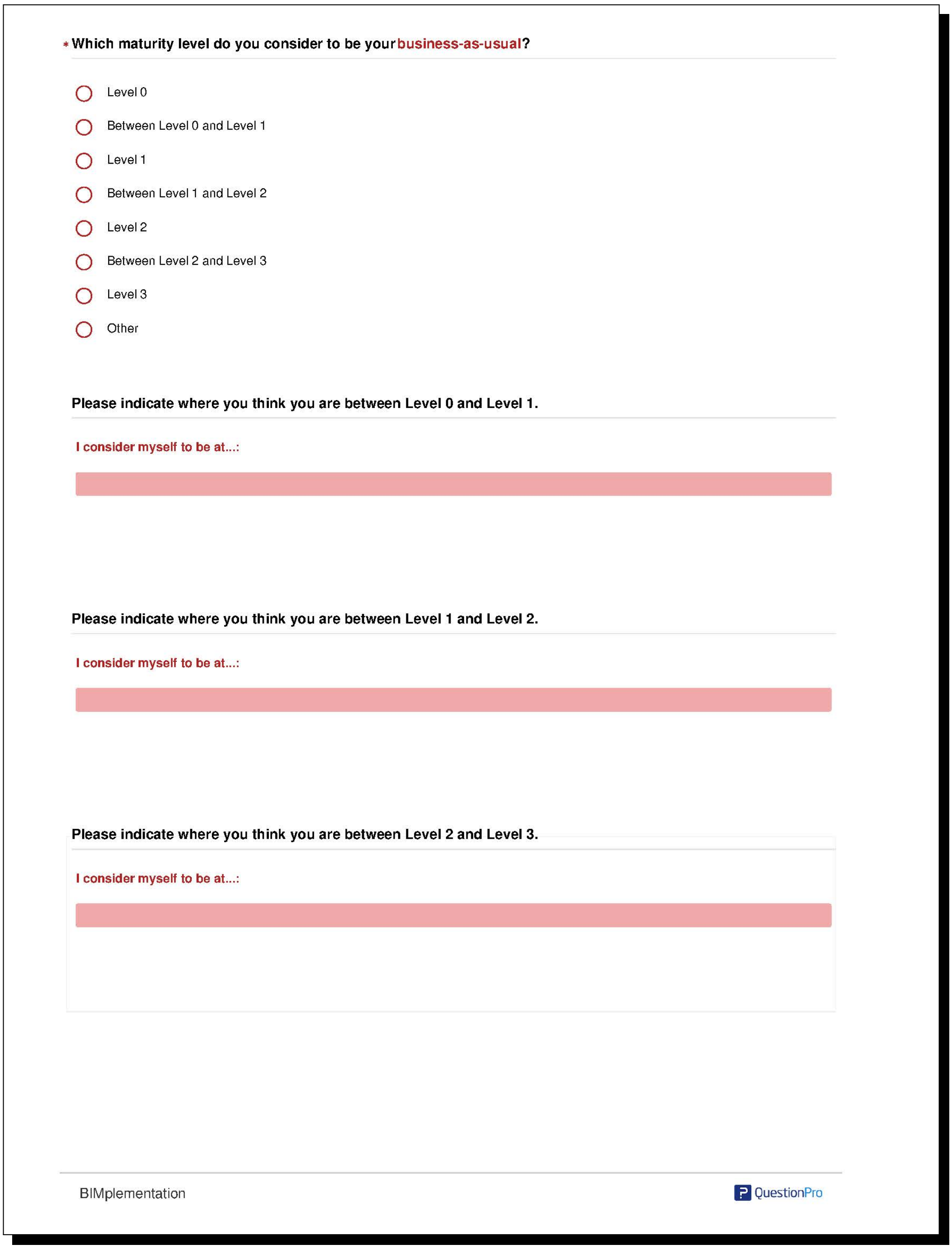
- ○ Yes - I am aware of BSRIA's Soft Landings.
- ○ Yes - I am aware of the Government's Soft Landings.
- ○ Yes - I am aware of both sets of Soft Landings.
- ○ I am not aware of either.

Thank you for your input!

We'd love to hear more about your involvement with BIM. Would you like to help further by answering another set of questions regarding your BIM usage?

- ○ Yes
- ○ No

BIMplementation QuestionPro



* Which maturity level do you consider to be your business-as-usual?

- Level 0
- Between Level 0 and Level 1
- Level 1
- Between Level 1 and Level 2
- Level 2
- Between Level 2 and Level 3
- Level 3
- Other

Please indicate where you think you are between Level 0 and Level 1.

I consider myself to be at...:

Please indicate where you think you are between Level 1 and Level 2.

I consider myself to be at...:

Please indicate where you think you are between Level 2 and Level 3.

I consider myself to be at...:

BIMplementation QuestionPro

* **How confident are you in your overall competency in BIM?**

- ○ Very confident
- ○ Quite confident
- ○ In between
- ○ Not very confident
- ○ Not at all confident

Please rate your competency in each of the following standards from 0 to 10.

If you have not heard of the standard, please ensure the box reads 0.

BS 8536-2: 2016

BS 1192: 2007 + A2: 2016

PAS 1192-3: 2014

BS 8536-1: 2015

PAS 1192-6: 2018

PAS 1192-5: 2015

BIMplementation QuestionPro

BS 1192-4: 2014

PAS 1192-2: 2013

BS 15978: 2011

Do you use any BIM standards that have been developed in-house by your organisation?

- ◯ Yes
- ◯ No

Which of the following statements best describe how you interact with aCommon Data Environment (CDE)?

Select all that apply.

- ☐ I exchange digital information within a CDE.
- ☐ I manage digital information within a CDE.
- ☐ I receive and review digital information created by others in a CDE.
- ☐ I create digital information with embedded or associated attributes in a CDE.
- ☐ I do not use a CDE.

How often do you interact with a CDE?

- ◯ For all projects
- ◯ For most projects
- ◯ For some projects

BIMplementation QuestionPro

Which of the following delivery formats do you typically interact with on a project?

Select all that apply.

- ☐ 4D time simulated models
- ☐ Individual 3D digital design or construction models with embedded or linked attributes
- ☐ Simulations and visualisations
- ☐ Federated 3D models
- ☐ 2D information, created from scratch (e.g. on CAD software)
- ☐ 2D information generated from a 3D model
- ☐ IFC files
- ☐ Design analysis outputs
- ☐ 6D "as-built" model with operational data
- ☐ 5D costs for model attributes
- ☐ COBie datasets
- ☐ None of the above

Roughly, what percentage of information is generated from a single 3D model environment?

%

Do you produce information for use within anAsset Information Model (AIM)?

- ◯ Yes
- ◯ No

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QuestionPro

Which of the following activities are you involved with?

Select all that apply.

- ☐ Defining client's requirements/needs
- ☐ Conducting Post-Occupancy Evaluation (POE)
- ☐ Generating non-proprietary file formats for exchange purposes
- ☐ Organising information using a classification system
- ☐ Validating non-graphical datasets e.g. testing COBie for completeness
- ☐ Engaging in stakeholder discussions during conception/brief stages
- ☐ Using visualisation as a design communication tool
- ☐ Sourcing BIM objects from a library
- ☐ Resolving issues using clash detection and 3D coordination
- ☐ Participating in discipline model reviews
- ☐ Producing BIM objects to a standard
- ☐ None of the above

Do you use a file naming convention?

- ○ Yes, on all digital information.
- ○ Yes, on most digital information.
- ○ Yes, on some digital information.
- ○ No, not at all.

Are there suitable strategies/protocols in place regarding digital security for the work you are involved with?

- ○ Yes
- ○ No

Do you currently use BIM-enabled software?

This includes BIM viewers, CDE hosting tools, design software, simulation/analysis tools, etc.

- ○ Yes
- ○ No

BIMplementation QuestionPro

To what extent are you familiar with each of the following documentation?

If you have not heard of the document, please ensure the box reads 0.

Standard Methods and Procedures (SMP)

Asset Information Requirements (AIR)

Employer Information Requirements (EIR)

Plain Language Questions (PLQ)

Organisation Information Requirements (OIR)

Master Information Delivery Plan (MIDP)

Project Implementation Plan (PIP)

CIC BIM Protocol

BIMplementation

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BIM Execution Plan (BEP)

Task Information Delivery Plan (TIDP)

How strongly do you agree or disagree with the following statements:

Using BIM and Information Management processes...

... helps me synchronize with other project team members.

Strongly Disagree

... saves my time.

Strongly Disagree

... decreases my productivity.

Strongly Disagree

...makes me aware of important information from other project team members.

Strongly Disagree

...helps me adjust to changing conditions within project teams.

Strongly Disagree

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... improves service to the client.

Strongly Disagree

... helps me meet client needs.

Strongly Disagree

... has improved my coordination with other project team members.

Strongly Disagree

... allows me to accomplish more work than would otherwise be possible.

Strongly Disagree

... improves client satisfaction.

Strongly Disagree

Use the slider to indicate how strongly you agree or disagree with the statements below.

I do not intend to continue using BIM.

Strongly Disagree

The information that BIM tools and processes provides to me is accurate.

Strongly Disagree

It is difficult for me to do my job effectively because some of the data I need is missing from the BIM applications and processes.

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Strongly Disagree

I plan to continue using
BIM.

Strongly Disagree

The data accessible from BIM applications and processes lacks critical information that would be useful to
me.

Strongly Disagree

The information from BIM applications and processes has numerous accuracy problems that make it difficult for me to do my
job.

Strongly Disagree

I predict I would continue using BIM
.

Strongly Disagree

BIM data that I use or would like to use are accurate enough for my
purposes.

Strongly Disagree

The data that BIM provides is exactly what I need to carry out my
tasks.

Strongly Disagree

BIM provides the right data to meet my
needs.

Strongly Disagree

The data I receive from BIM tools and processes is
true.

Strongly Disagree

BIMplementation QuestionPro

Finally, we just want to ask you a few questions about yourself and your organisation.

Using the scales below, which do you personally prefer?

	1	2	3	4	5	
Low-risk projects (with a guaranteed but moderate return on investment).	○	○	○	○	○	High-risk projects (with a chance of high return on investment).
Gradual and moderate reactions to outside changes.	○	○	○	○	○	Aggressive and far-reaching reactions to outside changes.
To introduce changes after competitors.	○	○	○	○	○	To introduce changes before competitors.
Time tested methods.	○	○	○	○	○	Innovation.

Please indicate your opinions of using BIM by using the scale below.

	1	2	3	4	5	
Using BIM is a bad idea.	○	○	○	○	○	Using BIM is a good idea.
I dislike the idea of using BIM.	○	○	○	○	○	I like the idea of using BIM.
Using BIM is a foolish idea.	○	○	○	○	○	Using BIM is a wise idea.

BIMplementation QuestionPro

Think about your ability to do the tasks required by your job.

To what extent do you agree or disagree with the statements below?

I have all the skills needed to perform my job very well.

Strongly Disagree

My future in this job is limited because of my lack of skills.

Strongly Disagree

I have confidence in my ability to do my job.

Strongly Disagree

There are some tasks required by my job that I cannot do well.

Strongly Disagree

I am very proud of my job skill and abilities.

Strongly Disagree

Most people in my line of work can do this job better than I can.

Strongly Disagree

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QuestionPro

Including yourself, approximately how many people are employed in your organisation?

- ◯ 1-5
- ◯ 6-10
- ◯ 11 - 25
- ◯ 26 - 50
- ◯ 51 - 100
- ◯ 101 - 250
- ◯ 251 - 500
- ◯ 501 - 1000
- ◯ > 1000

* **Please specify where your office is based.** ?

- ◯ England
- ◯ Scotland
- ◯ Wales
- ◯ Northern Ireland
- ◯ Other

Please indicate in which region you are based.

Which of the following best describes the organisation you currently work for? ?

If other, please specify:

BIMplementation QuestionPro

* **Please enter your specific role within the organisation.**

* **Which of the following best describes your job with respect to level within the organisation?**

- ◯ Executive/Senior Management
- ◯ Middle Management
- ◯ Professional
- ◯ Supervisory
- ◯ Technical (e.g. Technician)
- ◯ Operative (e.g. Workforce)
- ◯ Other

* **On a typical project, which of the following project stages are you involved in?**

Select all that apply.

- ☐ Procurement
- ☐ Preparation and Brief
- ☐ Design
- ☐ Build and Commission
- ☐ Operation

Please identify the type of projects your organisation is typically involved with.

Select all that apply.

	Public-Sector	Private-Sector	New-Build	Refurbishment
Commercial/Social	☐	☐	☐	☐
Residential	☐	☐	☐	☐
Infrastructure	☐	☐	☐	☐

BIMplementation QuestionPro

* **How many years experience do you personally have...**

(i) ... working in the UK's AECO sector?

(ii) ... working for your current organisation?

(iii) ... using BIM in any capacity?

* **What is the highest level of education that you have completed to date?**

- ○ Doctorate (PhD)
- ○ Postgraduate Degree (MA, MSc, etc.)
- ○ Undergraduate Degree (BA, BSc, etc.)
- ○ Further Education (HNC, HND, etc.)
- ○ Secondary Education (GCSE, Scottish Standard Grades, A-Levels, etc.)

* **Are you a member of an industry body or professional organisation?**

- ○ Yes
- ○ No

Have you personally undergone any form of BIM-specific training or third party certification?

E.g. undertaking CPD credits, attending in-house training, attending external events, software training, etc.

- ○ Yes
- ○ No

BIMplementation

QuestionPro

Finally, if you have any further comments regarding the challenges surrounding BIM upskilling and competencies, please feel free to use the box below.

Thank you for completing the survey!

If you are happy for us to contact you to discuss your answers further, please leave your details below.

Leave blank if you do not wish to be contacted.

First Name

Last Name

Phone

Email Address

Would you like to be sent a summary of any published findings?

- Yes
- No

BIMplementation

QuestionPro

D.3. Invitation Email

Dear [*insert name*],

Invitation to participate in a BIM Implementation Questionnaire Survey

As a member of the UK's Architecture, Construction, and Operation (AECO) sector, you are kindly invited to participate in a research study. At Edinburgh Napier University, we have developed an online survey instrument as part of doctoral research exploring the impact of individual levels of understanding on the adoption of Building Information Modelling (BIM). Whether you consider yourself to have adopted BIM or not, your honest opinions are valuable to us.

The survey is estimated to take around 15-18 minutes to complete. You are encouraged to read each question carefully and to not skip an item. More information can be found in the attached sheet. The link to the online study can be accessed below:

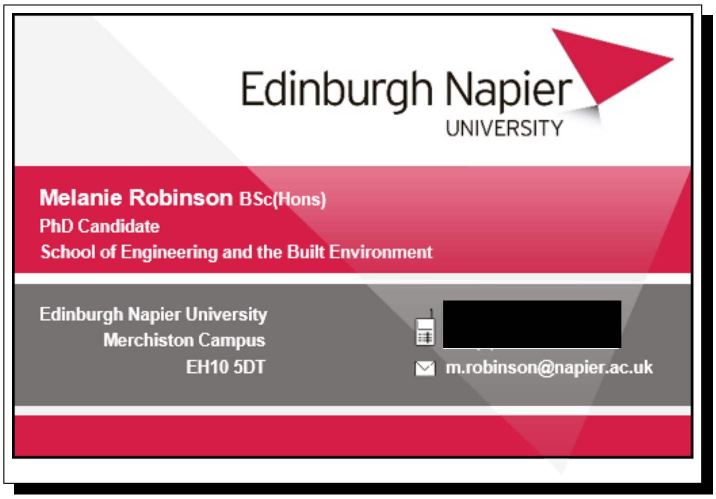
************** LINK *****************

Your cooperation by responding to the questionnaire is a critical component of the PhD process. As a thank you, an opportunity to receive a summary of the results can be made available. Please indicate your interest by providing your contact details when prompted at the end of the questionnaire.

Best regards,

Melanie Robinson

D.4. Business Card Hand-Outs



Appendix E

E.1. Phase I: Job Roles

Original Job Role	Job Role Classification
BIM Coordinator Coordinator Model Coordinator	BIM Coordinator
BIM Consultant BIM Manager BIM Specialist Consulting Information Manager Digital Construction Process Manager Enginneering Systems Manager Group BIM Manager Project BIM Manager Project Information Manager Senior BIM Consultant	BIM Manager
BIM Technician	BIM Technician
Cost Consultant Order Processor Quantity Surveyor	Cost Consultant
Architect Architectural Technician Architectural Technologist Design Engineer Design Manager Designer Engineer Framework Manager overseeing design team Graduate Civil Engineer Highway Engineer Lead Designer Principal Consultant Principal Designer Senior Mechanical Engineer Structural Engineer Structural Technician Surveyor	Design Consultant

Continued on next page

Table E.1 – *Continued from previous page*

Original Job Role	**Job Role Classification**
Sustainability Expert	
Assistant Site Manager Site Engineer	Contractor
CEO CTO Director Director of Projects Global BIM Director	Director / Chair
Intern	Intern
BIM Lead	Lead / Head

E.2. Wordcloud: Job Roles

E.3. Respondent Distribution by Job Role

Generalised Job Role	**Total Responses**		**Opted-In Responses**	
	Frequency	Percent	Frequency	Percent
BIM Consultant, of which are:	20	26.3	15	35.7
BIM Coordinator	*5*	*6.6*	*3*	*7.1*
BIM Manager	*14*	*18.4*	*11*	*26.2*
BIM Technician	*1*	*1.3*	*1*	*2.4*
Contractor	2	2.6	0	-
Cost Consultant	3	3.9	0	-
Design Consultant, of which are:	21	27.6	12	28.6
Architectural	*1*	*1.3*	*1*	*2.4*
Highways	*1*	*1.3*	*1*	*2.4*
MEP	*1*	*1.3*	*1*	*2.4*
Principal Designer	*1*	*1.3*	*1*	*2.4*
Structural	*1*	*1.3*	*1*	*2.4*
Sustainability	*1*	*1.3*	*1*	*2.4*
Unspecified	*1*	*1.3*	*1*	*2.4*
Director / Chief Role	14	18.4	5	11.9
Intern	1	1.3	0	-
Lead / Head	11	14.5	9	21.4
Project Manager	6	7.9	1	2.4
Senior Associate	2	2.6	1	2.4
Development / Training	1	1.3	1	2.4

Note: Several responses identified more than one job role.

E.4. Wordclouds: Institute Memberships

(a) Total sample

(b) Opted-in sample

E.5. BIM-related upskilling schemes

The below schemes were provided verbatim as part of the data gathering for the individual demographic data. Note: Some wording has been edited for clarity. Those marked with * were mentioned multiple times.

- BRE: Intro to BIM
- BRE: BIM Level 2 for Information Managers
- MSc BIM and Project Collaboration - Derby Uni
- In-house training*
- Lloyds registry
- BRE BIM AP*
- BRE BIM Training Programme / BIM Essentials*
- Revit / Revit Essentials Training*
- BSi Accreditation
- External events*
- BSRIA training courses on BIM
- Software Training (in-house)*
- Software Training (external)*
- RICS BIMM course*
- BRE Academy BIM Level 2 Certification*
- Online Webinars
- YouTube
- Local User Group Seminars
- Autodesk Reseller Training
- MSc Middlesex University*
- MSc BIM and Project Collaboration - Derby Uni
- CPD Sessions

Appendix F

F.1. Rasch Analysis: Item Fit Statistics

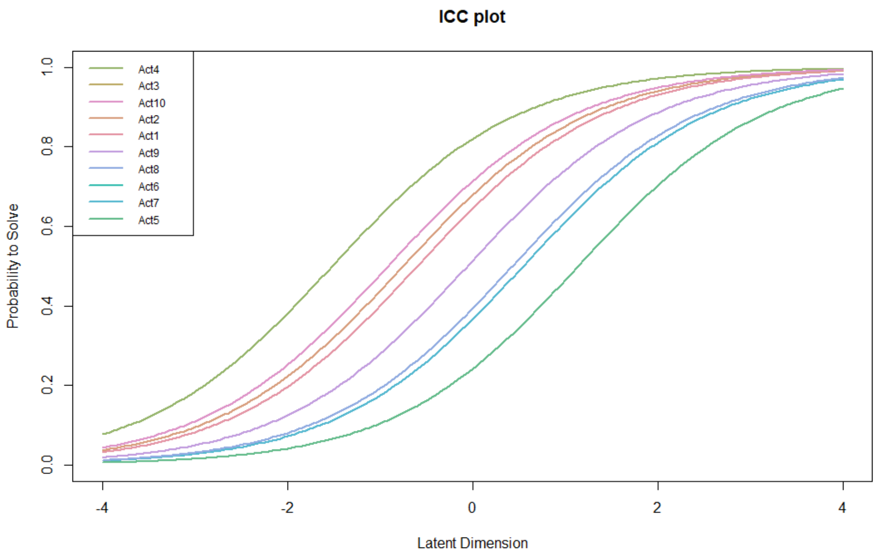
Item	*T*	*b*	SE	Infit		Outfit		PTMC
				Msq	Zst	Msq	Zst	
FORM6	8	2.71	0.45	0.90	-0.29	1.10	0.35	0.47
FORM7	12	2.02	0.39	1.19	0.94	1.34	1.06	0.33
FORM5	16	1.45	0.37	0.97	-0.15	1.06	0.34	0.50
ACT5	18	1.19	0.36	0.96	-0.19	0.99	0.05	0.50
CDE4	18	1.19	0.36	0.76	-1.59	0.66	-1.66	0.67
FORM3	21	0.82	0.35	1.08	0.58	1.34	1.44	0.40
CDE2	22	0.69	0.35	0.84	-1.17	0.76	-1.07	0.59
ACT6	23	0.57	0.35	0.80	-1.49	0.70	-1.31	0.62
ACT7	23	0.57	0.35	1.04	0.30	1.15	0.68	0.42
ACT8	24	0.45	0.35	1.35	**2.31**	**1.91**	**2.91**	0.16
FORM10	26	0.20	0.36	1.11	0.80	1.06	0.32	0.37
ACT9	28	-0.06	0.36	1.07	0.54	1.14	0.51	0.35
CDE3	28	-0.06	0.36	1.06	0.48	1.05	0.24	0.37
CDE1	30	-0.33	0.38	0.84	-1.03	0.79	-0.45	0.51
FORM4	31	-0.48	0.38	1.00	0.03	0.88	-0.14	0.39
ACT1	32	-0.63	0.39	0.81	-1.04	0.60	-0.86	0.52
FORM11	32	-0.63	0.39	1.18	0.98	1.38	0.90	0.21
ACT2	33	-0.79	0.41	0.85	-0.73	0.59	-0.78	0.49
ACT3	34	-0.96	0.42	0.78	-0.96	0.53	-0.85	0.51
ACT10	34	-0.96	0.42	1.20	0.92	1.21	0.54	0.18
ACT4	37	-1.59	0.50	0.97	0.03	0.69	-0.19	0.31
FORM2	37	-1.59	0.50	0.78	-0.62	0.44	-0.67	0.46
FORM9	37	-1.59	0.50	1.04	0.22	1.85	1.14	0.15
FORM1	39	-2.20	0.62	1.06	0.29	1.65	0.88	0.11
Mean	26.8	.00	0.40	0.98	.00	1.04	0.10	-
σ	8.2	1.20	0.07	0.16	0.90	0.39	1.00	-

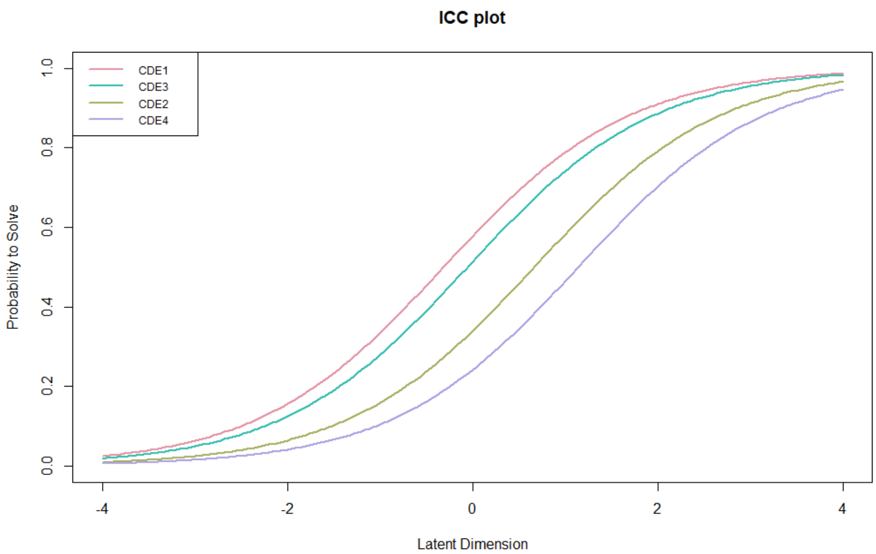
Note: SE = Standard Error, *b* = Item Difficulty, PTMC = Point-Measure Correlation, σ = Standard Deviation.

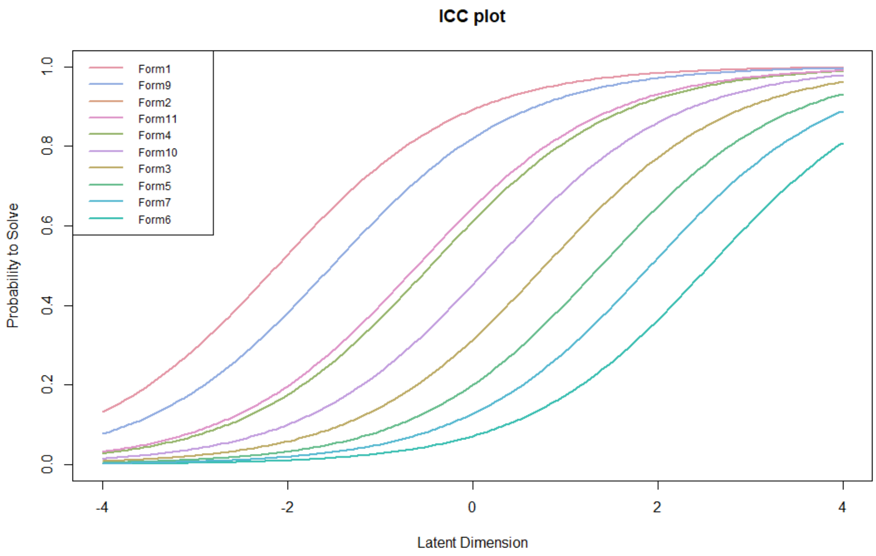
Item	T	b	SE	Infit		Outfit		PTMC
				Msq	Zst	Msq	Zst	
FORM6	8	2.82	0.46	0.96	-0.06	1.11	0.38	0.49
FORM7	12	2.09	0.40	1.19	0.94	1.39	1.10	0.37
FORM5	16	1.50	0.37	0.97	-0.10	1.14	0.60	0.50
ACT5	18	1.23	0.36	0.96	-0.21	1.03	0.20	0.51
CDE4	18	1.23	0.36	0.78	-1.42	0.68	-1.52	0.65
FORM3	21	0.85	0.36	1.09	0.65	1.35	1.51	0.41
CDE2	22	0.72	0.36	0.86	-0.97	0.78	-1.01	0.58
ACT6	23	0.60	0.36	0.81	-1.37	0.71	-1.32	0.60
ACT7	23	0.60	0.36	1.10	0.72	1.28	1.20	0.39
FORM10	26	0.22	0.36	1.11	0.83	1.14	0.60	0.37
ACT9	28	-0.05	0.37	1.08	0.57	1.16	0.59	0.36
CDE3	28	-0.05	0.37	1.08	0.59	1.08	0.37	0.37
CDE1	30	-0.32	0.38	0.84	-0.96	0.92	-0.11	0.49
FORM4	31	-0.47	0.39	1.01	0.12	0.94	-0.03	0.39
ACT1	32	-0.62	0.40	0.82	-0.95	0.61	-0.92	0.51
FORM11	32	-0.62	0.40	1.23	1.20	1.62	1.37	0.19
ACT2	33	-0.79	0.41	0.87	-0.59	0.61	-0.81	0.47
ACT3	34	-0.96	0.43	0.79	-0.93	0.54	-0.89	0.50
ACT10	34	-0.96	0.43	1.20	0.89	1.20	0.54	0.21
ACT4	37	-1.60	0.50	0.99	0.09	0.75	-0.14	0.30
FORM2	37	-1.60	0.50	0.74	-0.74	0.41	-0.79	0.47
FORM9	37	-1.60	0.50	1.04	0.23	2.31	1.56	0.15
FORM1	39	-2.22	0.62	1.08	0.32	1.71	0.93	0.11
Mean	26.9	.00	0.41	0.98	.00	1.06	0.10	-
σ	8.4	1.25	0.07	0.14	0.80	0.42	0.90	-

Note: SE = Standard Error, b = Item Difficulty, PTMC = Point-Measure Correlation, σ = Standard Deviation.

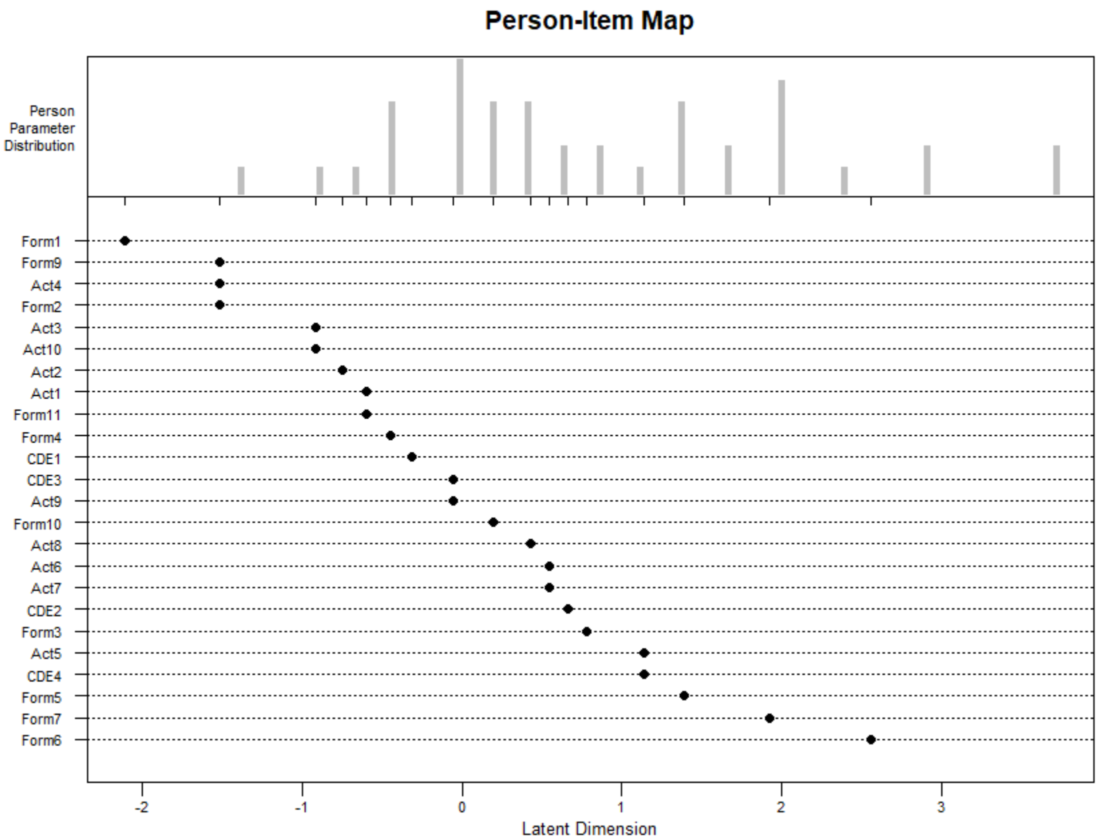
F.2. Rasch Analysis: Item Characteristic Curves







F.3. Rasch Analysis: Person-Item Map



F.4. Loadings and Cross-Loadings for the Reflective Measurement Model

	AI	PB-DP	PB-DQ
AI01	**0.952**	0.290	0.330
AI02	**0.835**	0.143	0.242
AI03	**0.933**	0.399	0.401
AI04	**0.784**	0.215	0.193
DP01r	0.293	**0.847**	0.225
DP02	0.320	**0.894**	0.329
DP03	0.145	**0.747**	0.298
DP04	0.175	**0.797**	0.471
DP05	0.327	**0.824**	0.541
DQ01	0.093	0.305	**0.808**
DQ02	0.136	0.420	**0.851**
DQ03	0.214	0.431	**0.854**
DQ04	0.464	0.389	**0.849**
DQ05	0.241	0.390	**0.753**
DQ06r	0.153	0.384	**0.677**
DQ07	0.512	0.260	**0.727**

Note: "r" denotes reverse-coded item.

Note: AI = Attitudinal Intent to Continue Use, PB = Perceived Benefits, DP = Delivery Performance, DQ = Data Quality.