Development of Conceptual Constructs for Organisational BIM Adoption and their Systematic Application within the UK Architecture Sector

Submitted by
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DECLARATION

I hereby declare that no part of this thesis has previously been submitted for any degree of qualification at this, or any other University or Institute of learning.

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ABSTRACT

Building Information Modelling (BIM) is an innovation that is transforming practices within the Architectural, Engineering, Construction and Operation (AECO) sectors. The investigation of the process of BIM adoption and diffusion has attracted significant interest from industry and academia. Drivers and factors influencing BIM adoption were examined at different levels, ranging from individual and group through organisations and supply chains to whole market level. However, there is still a dearth of studies that extensively integrate drivers and factors affecting the decision to adopt BIM by organisations. Existing studies often seek to develop approaches for forecasting BIM diffusion, and are generally focused on the diffusion phase, after BIM has been adopted. Therefore, this study aims to improve the understanding of the BIM adoption process within organisations and across markets by developing the necessary conceptual constructs (e.g., BIM adoption taxonomy, adoption process model, adoption two-dimensional characterisation model, and systems thinking models) and providing the supporting empirical evidence.

This study provided an in-depth analysis of the BIM adoption process within organisations. It developed a unified BIM adoption taxonomy that contains an extensive array of adoption factors. Following the validation of the taxonomy, its factors were used within a proposed conceptual model, which combined the Innovation Diffusion Theory with the Institutional Theory, to perform a multifaceted analysis of the BIM adoption process. A set of 11 most influencing factors on BIM adoption process was identified and included: *Willingness to adopt BIM*, *Communication behaviour of an organisation*, *Observability of BIM benefits*, *Compatibility of BIM*, *Social motivations among organisation's members*, *Relative advantage of BIM, Organisational culture*, *Top management support*, *Organisational readiness*, *Coercive pressures (Governmental mandate, informal mandate)*, and *Organisation size*. Focussing on these 11 most influencing factors, several analyses were performed to understand the interplays between these factors - while considering specific instances of certain factors (i.e. organisation size, and external isomorphic pressure) over time (i.e., Pre-2011, 2011-2016, and Post-2016 exemplifying three key time periods in the UK national BIM strategy). The results showed that the *Relative advantage of BIM* is the most important and influencing factor across all the three stages of the adoption process (i.e., Awareness stage, Intention stage, and Decision stage) of the BIM adoption process. Coercive pressures (e.g. Governmental mandate, informal mandate) had a direct influence on both formulating the intention and the decision to adopt BIM across the three-time horizons (i.e., Pre-2011, 2011-2016, and Post-2016). For the Pre-2011 period, the *coercive pressures* were mostly informal mandate/pressures by the parent companies and partners, while during 2011-2016 and Post-2016 periods, it is predominantly the UK Government mandate which was announced in 2011 and entered into effect in 2016. Several Systems Thinking models were developed to show the interdependencies among the factors that affect the BIM adoption process at different time periods and stages of the BIM adoption process. Such models infer patterns of behaviour of BIM adoption as complex

systems and can be used to guide the development and implementation of BIM strategies. For example, by relating each factor within the system thinking model to the player group(s) who can exert influence upon it, the complementary role of the player groups can be planned to facilitate the BIM adoption process according to the patterns identified in the corresponding systems thinking model. The different patterns developed through the specialised systems thinking models can be used to develop tailored BIM adoption strategies for the different scenarios involved.

At a global level (overall aim), this study provided an understanding of how intra-organisational BIM adoption and inter-organisational BIM diffusion occurs. At a local level (individual objectives), the key knowledge deliverables in this study (i.e., the taxonomy, conceptual model for BIM adoption process, two-dimensional characterisation model of BIM adoption, and systems thinking models) and the empirical investigation represent a new contribution to knowledge with each contributing from a specific standpoint. The Unified BIM Adoption Taxonomy is the first – if not the sole – statistically validated BIM adoption taxonomy that includes an extensive array of adoption drivers and factors and combines constructs from both the Institutional and the Innovation Diffusion theories. The conceptual model for analysing BIM adoption and its use for the empirical investigation of BIM adoption within the UK Architecture sector explored and identified relationships that were not known before (i.e., triggering the BIM Awareness and formulating an Intention about BIM adoption is not limited to Internal Environment Characteristics and the Innovation Characteristics respectively - as suggested by Rogers' theory, but occurs by a combination of both characteristics). The two-dimensional characterisation model of BIM adoption clarified new interplays between adoption factors, the organisation size, and time (i.e., pairs of positively and negatively correlated factors vary based on time horizon). The classification of factors into cause and effect groups using the F-DEMATEL provided a new understanding of the independencies between factors which can be used to tailor and prioritise implementation actions and investments. The developed Systems Thinking Models enabled an attentive analysis of mutual interactions between adoption factors as part of a causal relationship networks. The developed instances of such models for different temporal scenarios and stages of the BIM adoption stage can be exploited by the industry player groups (i.e., Policy-makers, decision-makers, change agents, etc.) to promote BIM adoption process within the organisations and BIM diffusion across a market.

The key knowledgeable deliverables can be used to perform various analyses of the BIM adoption process, providing evidence and insights for decision-makers within organisations and across a whole market when formulating BIM adoption and diffusion strategies. In particular, they can assist researchers, decision-makers, and policy-makers with a better understanding of the BIM adoption process and can guide the development of BIM strategies and plan for BIM adoption and diffusion. Ultimately, they contribute to promote BIM adoption within the architectural sector through the suggested adoption patterns.

LIST OF PUBLICATIONS

- **Published article in a leading journal (*Automation in Construction*)[a]:**

– AHMED, A. L. & KASSEM, M. 2018. A unified BIM adoption taxonomy: Conceptual development, empirical validation and application. *Automation in Construction,* 96**,** 103-127. https://doi.org/10.1016/j.autcon.2018.08.017

- **Published conference papers:**

– AHMED, A., KAWALEK, J. & KASSEM, M. 2017. A Conceptual Model for Investigating BIM Adoption by Organisations. *LC3 2017: Volume I – Proceedings of the Joint Conference on Computing in Construction (JC3).* Heraklion, Greece. https://doi.org/10.24928/JC3-2017/0103

– AHMED AHMED, L., KAWALEK JOHN, P. & KASSEM, M. 2017. A Comprehensive Identification and Categorisation of Drivers, Factors, and Determinants for BIM Adoption: A Systematic Literature Review. *Computing in Civil Engineering 2017*. https://doi.org10.1061/9780784480823.027

- **Forthcoming publications:**

– Micro BIM adoption: A Multi-Variable Analysis of Adoption within the UK Architecture Sector

– Micro BIM Adoption: Identifying Cause and Effect Factors and Analysing their Inter-dependencies using a Fuzzy DEMATEL Approach

– Micro BIM adoption: The Profiling Patterns of adoption within UK Architecture Practices using a System Thinking Approach

[a] Some passages of the thesis have been quoted verbatim from this journal article.

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GLOSSARY OF ABBREVIATIONS AND TERMS

AEC	Architecture Engineering and Construction
2011-2016 Period	Trial implementation period of BIM mandate (UK Government BIM Strategy time-horizon)
BEP	BIM Execution Plan
BIM	Building Information Modelling
CFA	Confirmatory Factor Analysis
CLD	Causal Loop Diagram
COBie	Construction Operations Building Information Exchange
DEMATEL	Decision Making Trial and Evaluation Laboratory
F-DEMATEL	Fuzzy Decision Making Trial and Evaluation Laboratory
IDT	Innovation Diffusion Theory
INT	Institutional Theory
IPD	Integrated Project Delivery
OLR	Ordinal Logistic Regression
PIM	Project information model
Post-2016 Period	Post-mandate (UK Government BIM Strategy time-horizon)
Pre-2011 Period	Pre-announcement of BIM mandate (UK Government BIM Strategy time-horizon)
QA	Quality Assessment
RQs	Research Questions
SEM	Structural Equation Modelling
SLR	Systematic Literature Review
TAM	Technology Acceptance Model
UBAT	Unified BIM Adoption Taxonomy

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Chapter 1 | Introduction

1.1 Introduction

This chapter provides an overview of the research rationale and describes the research's problem, hypothesis, questions, aim and objectives. It also outlines the structure of the dissertation.

1.2 Research Rationale

In recent years, digital transformation and innovation have significantly permeated every topic within the construction sector, in both industrial and academic discourse. Since the inception of BIM, its connotation has always been on the rise. One of its latest definitions perceives "BIM as the "current expression of digital innovation within the construction sector" (Succar and Kassem, 2015, p.64)" (Ahmed and Kassem, 2018, p.104), "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format enabling multiple stakeholders to collaboratively design, construct and operate a facility throughout the building's life-cycle" (Succar, 2009, p.357). Given the growing importance of BIM, it is important to understand how intra-organisational BIM adoption and diffusion occurs and how organisations develop awareness, intention and decision to adopt BIM. The importance of investigating this topic stems from two directions: (1) successful adoption of BIM by organisations within the construction sector is obviously a necessary status to be achieved before the industry reap the acclaimed benefits from BIM-based digitalisation; and (2) most of the existing innovation adoption studies did not conceive BIM as a 'disruptive' and 'multifaceted'. Hence, this research argues for the need to better understand intra-organisational BIM adoption and diffusion.

The remainder of this sector further elaborates on the disruptive and multi-faceted nature of BIM as innovation and explain how existing academic and industry literature accounts for these BIM characteristics.

BIM adoption entails an unsettling period when adopters require to adapt new technologies and processes and is affected by economic and social variables (Ahmad et al., 2016). Except a few of the earliest definitions of BIM as being "process innovation" (Utterback and Abernathy, 1975; Damanpour and Gopalakrishnan, 2001), all new definitions recognised its multifaceted nature. For example, in the framework introduced by Succar (2009), the multifaceted aspects of BIM were demonstrated in three interlocking domains of BIM knowledge/nodes: policy, technology, and process.

In addition to the issue related to recognising the disruptive and multifaceted nature of BIM, most studies on BIM awareness, adoption, and usage across multiple countries were industrial reports and surveys and lacked the level of rigour and evidence required in research-driven examinations. Academic studies are also available and offer more insights about the process of BIM adoption within organisations than industry reports and surveys. However, much of these studies do not provide assistance to policy-makers and decision-makers by e.g., informing BIM adoption policies, and investigating interplays between market-wide drivers (i.e. a mandate to use BIM) and organisation-level drivers (i.e. size of the organisation, top management support, among many others). The existing literature shortcomings are caused by (1) the consideration of a partial array of adoption drivers and (2) the adoption of specific theoretical lenses (e.g., Technology Acceptance Model) that delimit the consideration of an extensive set of drivers; (3) research design that does not enable the linking of the investigative effort (i.e. innovation adoption results) to policy maker's topics (i.e. market-wide BIM implementation strategies).

As a result of these early deliberations – that will be further elaborated upon in the next Section– it can be concluded that BIM warrants new innovation adoption studies.

1.3 Research Problem Identification

The investigation of the "process of BIM adoption and diffusion has attracted considerable attention from industry and academia. Although the drivers and factors influencing BIM adoption were examined at different levels – ranging from individual and group through organisations and supply chains to whole market level – however, there is still a shortage of studies that extensively integrate drivers and factors affecting the decision to adopt BIM by organisations" (Ahmed and Kassem, 2018, p.103). This includes:

Existing studies often seek to develop approaches for forecasting BIM diffusion, and are generally focused on the diffusion phase, after BIM has been adopted (Zhang and Hu, 2011; Gledson, 2015; Sunil et al., 2015; Tang and Yi, 2015; Gholizadeh et al., 2018). For instance, using 'Bass Model' to predict the rate of BIM technologies diffusion within a certain period (i.e., 2012 – 2022) of the Chinese construction industry (Tang and Yi, 2015).

There are also critical shortcomings in existing BIM adoption studies include the use of key terms and concepts (e.g., implementation, readiness, adoption, diffusion) interchangeably. For example, (Al-Shammari, 2014), (Haron et al., 2014), (Wu and Issa, 2014), (Attarzadeh et al., 2015), (Ding et al., 2015), and (Hosseini et al., 2015) have all interchangeably used the terms 'Adoption' and 'Implementation'. "This blurs the distinction between interrelated concepts such as adoption, implementation, and diffusion" (Ahmed and Kassem, 2018, p.104).

In addition, lack of information about the position of studies in relation to the "innovation adoption stages (i.e., Awareness stage, Intention stage, and Decision stage)" (Ahmed and Kassem, 2018, p.111) which are proposed by Rogers (2003) in his innovation decision process. Moreover, the limited investigations of interplays between adoption factors and specific instances of some factors such as organisation size (i.e., micro, small, medium, and large) (Hosseini et al., 2016) and external isomorphic factors (e.g., market-wide BIM mandate by a government or a public agency) and how such interplays vary over time. Also, lack of investigative effort covering a whole sector (e.g., Architecture sector) within a "defined market (e.g., the United Kingdom). Finally, the dispersion in investigating the BIM adoption drivers and factors – across several studies – as a result of the specific theoretical lenses embraced by researchers. For instance, a study by Cao et al. (2014) investigated the influence of only the isomorphic pressures (i.e., Coercive, mimetic, and normative pressures) in isolation from other factors (i.e., innovation characteristics and internal characteristics) due to employing the Institutional Theory (INT) (Ahmed and Kassem, 2018). Another study focused on exploring the impact of only two factors, namely, Perceived ease of use and Perceived usefulness" (Ahmed and Kassem, 2018, p.104) on BIM adoption as the researchers implemented the theory of Technology Acceptance Model as a theoretical lens to guide the investigation (Takim et al., 2013).

The importance of the selected topic and the shortcomings in the literature on BIM adoption and diffusion motivated the overall aim of this study set next.

1.4 Study Hypothesis and Questions

This research has posed this hypothesis: "The decision to adopt BIM by architectural organisations – as a selected speciality cluster within the construction sector for this study – is a complex process entailing multiple stages that are mutually affected by several adoption drivers and factors. The understanding of this process can be achieved through the development and application of a conceptual model that allows the analysis of the effect by and interplays among an extensive array of adoption drivers" (Ahmed and Kassem, 2018, p.104).

To address the above hypothesis, the following initial specific questions have arisen:

(1) How the development of a unified BIM adoption taxonomy can inform the analysis and understanding the BIM adoption process by architectural organisations?

(2) What are the key drivers that affect BIM adoption within architectural organisations?

(3) "How both the BIM adoption taxonomy and the existing studies related to innovation adoption can be used to develop a conceptual model to guide the investigation of the BIM adoption process in architectural organisations?" (Ahmed and Kassem, 2018, p.109).

1.5 Aims and Objectives of the study

As shown in the previous section, this study starts with the proposition that the BIM adoption process by organisations warrants new theoretical insights and subsequent empirical investigations.

Aligned with this need, the overall aim of this study is to:

- Improve the "understanding of the BIM adoption process within organisations and across markets by developing the necessary conceptual constructs (e.g., BIM adoption taxonomy, adoption process model, adoption two-dimensional characterisation model, and systems thinking models) and providing the supporting empirical evidence" (Ahmed and Kassem, 2018, p.103).

To achieve this aim, six objectives are established:

- **Objective 1**– Identify "an extensive set of drivers and factors that influence the decision to adopt BIM by organisations, and the pertinent theoretical fundamentals and lenses" (Ahmed and Kassem, 2018, p.105);
- **Objective 2** – "Develop and validate a unified BIM adoption taxonomy of drivers and factors and a conceptual model to guide the empirical investigation of the BIM adoption process" (Ahmed and Kassem, 2018, p.103);
- **Objective 3** – Understand "the effect of the taxonomy's drivers and factors on the BIM adoption by Architectural practices within the United Kingdom by identifying the most influencing drivers and factors on each of the three adoption stages (i.e., awareness, interest, and decision to adopt) and analysing their comparative influence" (Ahmed and Kassem, 2018, p.113);

- **Objective 4** – Develop a two-dimensional characterisation model of BIM adoption including interplays between correlated pairs of adoption factors, and time (i.e., three time periods including pre-mandate period, implementation/trial period, and post-mandate period);
- **Objective 5** – Explore the BIM adoption process as a complex system through the application of structural modelling (i.e. Decision-making trial and evaluation laboratory – DEMATEL) to cluster adoption factors into cause and effect groups, and systems thinking techniques to map causal relationships and develop causal loop diagrams; and
- **Objective 6 –** Demonstrate how the results from the developed causal loop diagrams can inform the development and implementation of BIM adoption strategies.

1.6 Structure of the study

This study comprises nine chapters as follows:

Chapter 1 – Introduction: presents an overview of the research rationale and describes the research's problem, hypothesis, questions, aim and objectives. It also outlines the structure of the dissertation.

Chapter 2 – BIM – A Multifaceted and Disruptive Innovation?: provides the necessary evidence about the disruptive and multifaceted nature of BIM and justifies the need for a new BIM innovation adoption research. This chapter lays the foundation for the subsequent chapter (Systematic Literature Review).

Chapter 3 – Identifying BIM Adoption Drivers, Factors and Theoretical Fundamentals and Lenses: A Systematic Literature Review (SLR): conducts "a Systematic Literature Review to provide the theoretical prerequisites to develop a Unified BIM Adoption Taxonomy and a conceptual model" (Ahmed and Kassem, 2018, p.103) to empirically examine the process of BIM adoption within architectural organisations. This chapter addresses *Objective 1*.

Chapter 4 – Research Design and Methodology: provides an explanation of the methodological and philosophical choices that underpinned this research through a three-phase research approach to carry out. Also, it explains the general survey results.

Chapter 5 – Development of "a Unified BIM Adoption Taxonomy (UBAT) and BIM Adoption Process Conceptual Model: demonstrates the most widely used key terms and concepts explaining the diffusion of innovation processes and develops and validates a Unified BIM Adoption Taxonomy and a conceptual model for investigating BIM adoption decision by organisations" (Ahmed and Kassem, 2018, p.103). It addresses *Objective 2*.

Chapter 6 – The Most Influencing "Drivers and Factors Affecting the Decision to Adopt BIM by Architectural Organisations in the UK: identifies a set of the most influential factors affecting the decision to adopt BIM by the architectural organisations within the UK's market, ranked based on their power of influence at each stage of the BIM adoption process. It performs a retrospective analysis of BIM adoption within a market (i.e., the United Kingdom) by considering a sample of organisations that have already confirmed BIM adoption and crossed Stage III (i.e., Decision Stage)" (Ahmed and Kassem, 2018, p.107). This chapter addresses *Objective 3*.

Chapter 7 – A Two-dimensional Characterisation Model of the BIM adoption process for the UK Architectural Organisations: develops a Two-dimensional Characterisation Model for the BIM adoption process (Ahmed and Kassem, 2018, p.103) – which can help to better understand how pairs of factors can have different effects on various adoption stages across different time horizons – using knowledge synthesis. It addresses *Objective 4*.

Chapter 8 – Analysis of Causal Relationships among the Adoption Factors and Use of the Research Findings to Inform BIM Adoption Strategies: develops Fuzzy DEMATEL models and Systems Thinking Models to explore of the BIM adoption process as a complex system as a result of testing and demonstrates the usefulness of the study outcomes in informing the development and implementation of BIM adoption strategies. It addresses *Objective 5* and *Objective 6*.

Chapter 9 – Conclusion: demonstrates how all chapters of the thesis are linked and situated together, how the aim and objectives were addressed, and how the research questions were answered. Also, it shows how the thesis has contributed to the body of knowledge as well as the limitations and the recommendations for future research.

Figure 1.1 shows a roadmap of the study structure and applied methods

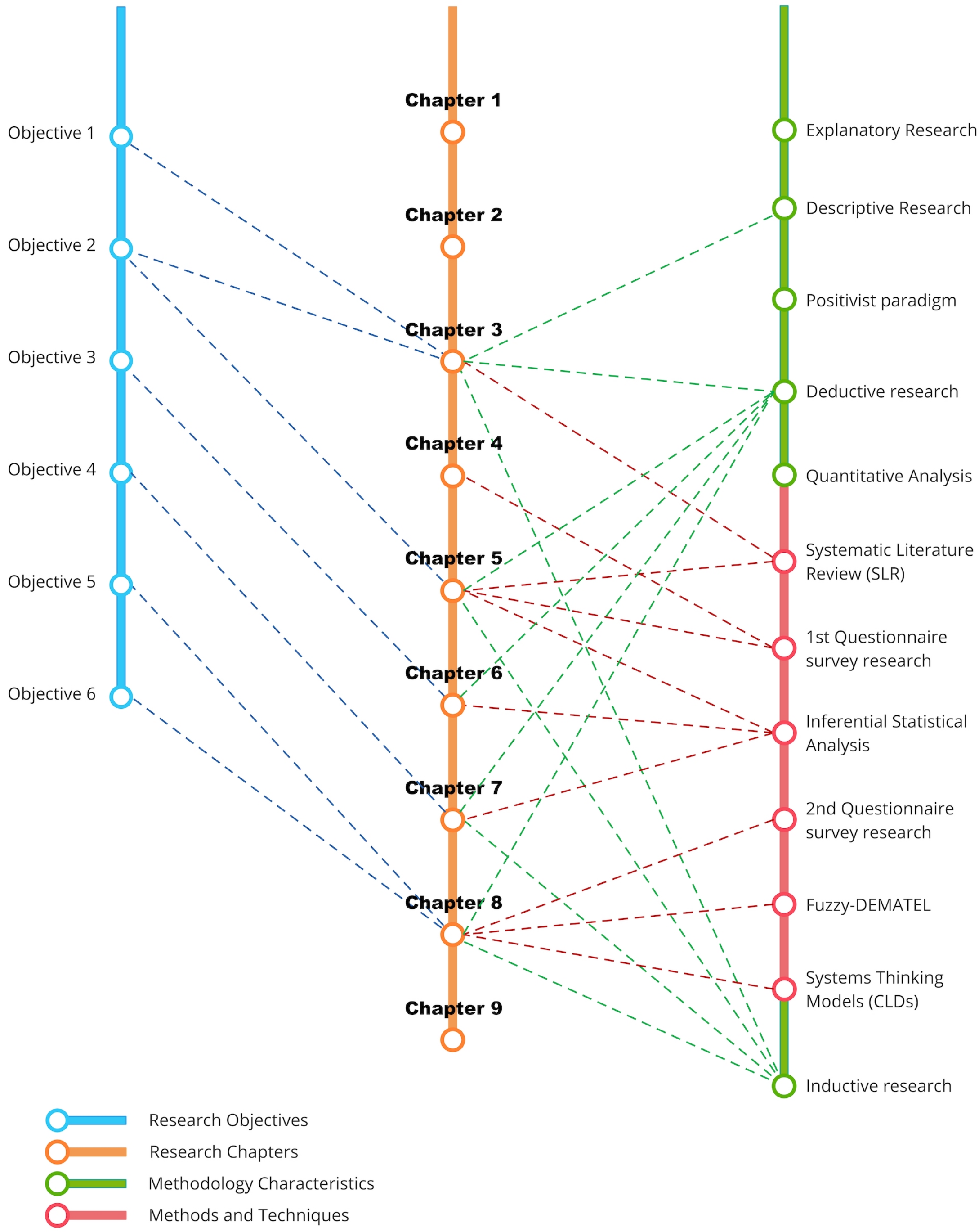


Figure 1.1 Roadmap of the Study Structure and applied Methods

Chapter 2 | BIM – A multifaceted and Disruptive Innovation?

2.1 Introduction

This chapter aims to provide background information about BIM and justify the need for a new BIM innovation adoption research. This is in part underpinned by providing evidence about the disruptive and multifaceted nature of BIM reported in the existing literature beyond the usual definitions. First, this chapter will review and analyse the most prominent BIM definitions. Second, the chapter will discuss BIM as innovation and provide evidence about its disruptive and multifaceted nature. Third, the chapter will illustrate the UK national BIM initiative as a use case exemplifying BIM as process, policy, and technology. Finally, the chapter will provide a succinct summary of existing BIM adoption/diffusion studies and conclude with the need for new BIM adoption studies.

2.2 What is BIM?

Over the past decade, numerous and various BIM definitions have been produced, bringing about misconception and perplexity with regards to the interpretation of the BIM value to the industry. There was a lot of controversy about the need for consistent definitions and terminology. Also, there were calls for consistency in depicting BIM, its frameworks, procedures and technologies, with a specific end goal to diminish the misconception in this field (e.g., Aranda-Mena et al., 2009; Goucher and Thurairajah, 2013; Brewer et al., 2012). Race (2012) indicates that there is no specific, agreed clarification or meaning of BIM definition. Every single definition made is from the point of view of its individual's disciplines, and hence, varies marginally from other different definitions.

From the Architecture, Engineering, and Construction (AEC) industry perspective, the wide range of BIM definitions can be laid into these areas: either BIM as a digital tool (i.e., a software), a conceptual process, or both. For example, Sabol (2008) defines BIM as a sophisticated software (i.e., technology) tool which facilitates in capturing information. Hardin (2011) labelled BIM as a virtual asset (i.e., building) in which the team members interact, through the intelligent objects of the asset, to improve the collaboration among the multidisciplinary team. In contrast, Ambrose (2007) describes BIM as a system of thinking (i.e., a conceptual position) and not a technology tool. On the other hand, Miettinen and Paavola (2014) contend that BIM is required to be investigated as "a multidimensional, historically evolving, and complex phenomenon". This allows BIM to be seen as a "digital representation, an object-oriented three-dimensional model, or an asset's digital repository" that facilitates the information exchange and interoperability among the pertinent platforms (Miettinen and Paavola, 2014). All the emerging definitions introduced based on the definer's expertise, focus, and their own explanation of BIM (Barlish and Sullivan, 2012), and reflect the transformative abilities and effect of BIM on the construction industry (Kassem et al., 2014).

In addition, even BIM as an acronym was criticised, when it first emerged, as an *ambiguous acronym/term* (Race, 2012) which might lead to confusion and extra expenditure. BIM as a "Buzzword" was usually adopted by software vendors to describe capabilities delivered by their products, until Eastman et al. (2008b, p.467) provided a clear definition of BIM as "*a verb or an adjective phrase to describe tools, processes and technologies such that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation*" and "*a modelling technology and associated set of processes to produce, communicate, and analyse building models*" (Eastman et al., 2011, p.11). Therefore, it represents an activity rather than an object. This definition is close to that of Succar (2009, p.357) who defines BIM as "*a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format enabling multiple stakeholders to collaboratively design, construct and operate a facility throughout the building's life-cycle*". Succar's definition delivers a comprehensive description of the BIM framework going beyond the usual other definitions, which tend to describe BIM as a Three-Dimensional (3D) software, and to consider BIM as Project Management (PM) tools and processes.

2.3 BIM – A Disruptive & Multifaceted innovation?

The following sections describe BIM as an innovation with a disruptive and multifaceted nature that affects the construction industry beyond the definitions.

2.3.1 BIM – A Disruptive innovation

BIM has been characterised as an 'innovation' (Barry, 2016; Davies and Harty, 2011; Davies and Harty, 2013; Elmualim and Gilder, 2014; Sebastian and van Berlo, 2010) and classified as a 'disruptive technology' (Eastman et al., 2008a; Watson, 2010; Succar et al., 2012; Kassem et al., 2014; Barry, 2016). According to the Business Dictionary (BusinessDictionary.com, Disruptive innovation), Disruptive innovation can be defined as "*The process of developing new products or services to replace existing technologies and gain a competitive advantage*". For instance, disruptive innovation inclines – within a classic innovative high-tech industry – to unsettle the market when it is displayed ostensibly that it usually needs further imaginative inner stance regarding the innovation improvement and promotion process. It is considerably harder for existed organisations to adopt this new disruptive innovation as it upsets and reverses the conventional plan of action and processes (ibid.).

The disruption occurred by BIM is not entirely focused on technology, but also involves economic and social aspects (Ahmad et al., 2016). Notwithstanding the slow adoption of digital innovations by the construction sector, particularly in correlation with different markets, BIM denotes a turning point regarding digitisation. BIM grips the capability to change the construction industry similarly that Amazon has reformed retail (Berger, 2017).

The disruption impact of BIM innovation can be manifested through three levels: Macro, Meso, and Micro. At the Macro level, BIM has transformed many aspects of the AEC industry (Sabongi and Arch, 2009; Eastman et al., 2008b), especially with the presence of the BIM mandate within specific markets/countries (e.g., the UK construction industry). In contrast with all other innovation systems, BIM is very different by the fact that attracted isomorphic pressures (e.g., a government mandate) which were not available for other information management systems. Therefore, the BIM mandate entails significant efforts of the local governments and the public sector to produce national-wide strategies, policies, and standards (Cabinet Office, 2011). At the Meso level, the BIM disruption can be mainly evident in the need to change the conventional inter-organisational relationships and contracts types among stakeholders involved in a BIM project (McAdam, 2010); sharing risk and rewards by project participants (Ghassemi and Becerik-Gerber, 2011); the implementation of Integrated Project Delivery (IPD) in BIM supply chain and procurement (Hatem, 2008); and technical collaboration (i.e., interoperability) and communication process among the project participants (Ghassemi and Becerik-Gerber, 2011). This infers, where project members are working together by BIM tools and procedures to convey a task, trust and clarity is essential (Sackey, 2014). Finally, at the Micro level, several intra-organisational aspects have been affected by the BIM disruption: BIM is a new innovation to the adopting organisation(s); a non-inconsequential conversion in nature; delivering competitive advantages; producing value to organisational planned results; predicting process related advantages; high possibility of uncertainty, vulnerability, and risk; and bringing in organisations from non-construction sector (Hosseini et al., 2015). However, the most significant disruption caused by BIM is the major change and shifting in established conventional technologies and processes embraced by organisations (Ahmad et al., 2016; Arayici et al., 2009), especially the dramatic conversion from traditional CAD (i.e., BIM Level 0) to the dual view of using of 2D/3D software technologies and processes (i.e., BIM Level 1) and targeting the collaborative objects/models and workflows (i.e., BIM Level 2) (Watson, 2010; Mihindu and Arayici, 2008). The hardness of recruiting manual draftsmen while the rapid acceleration of the BIM uptake with the fell of BIM cost (Watson, 2010) has caused requisites to reconsider organisational culture and organisation structure (Mom et al., 2014) to achieve the organisational readiness for BIM adoption (Succar and Kassem, 2015). In this regard, BIM push, also, can incur significant disruption; for instance, in relation to data responsibility and precision, and information stewardship (Morlhon et al., 2014); and interoperability amongst various BIM platforms and collaboration process among the members of a single organisation (Ghassemi and Becerik-Gerber, 2011; Ahmad et al., 2016).

These attributes may altogether lead to uncertainties when adopting BIM, hence, decision-makers tend to be influenced by the behaviours and practices of counterparts organisations and projects which hold likewise project features and institutional situations (Cao et al., 2014). Consequently, BIM adoption faces more challenges compared to those of other innovations in the AEC sector in the course of the most recent 30 years (Taylor, 2007).

2.3.2 BIM – A Multifaceted innovation

BIM is considered as a 'multifaceted' innovation (Arayici et al., 2011b; Guillermo et al., 2009; Hu et al., 2014). According to Succar (2009), in his proposed BIM framework, the multifaceted nature of BIM was demonstrated in three interlocking domains of BIM knowledge/nodes: policy, technology, and process. Damanpour and Gopalakrishnan (2001, p.48) identify two types of innovations: "*product innovation*" that is a "*new products or services introduced to meet an external user or market need*", and "*process innovation*" that is a "*new elements introduced into an organisation's production or service operations (e.g., input materials, task specifications, work and information flow mechanisms, and equipment) to produce a product or render a service*" (Utterback and Abernathy, 1975; Ettlie and Reza, 1992). In addition, the product innovation has a marketplace attention with customer driven, whilst the process innovation has an organisational focus with efficiency driven (Utterback and Abernathy, 1975), and the adoption of both is influenced by different factors that determine the degree to which the two innovations influence the adopting organisation (Tornatzky et al., 1990). Thus, BIM appears to be considered as a "process innovation".

Beyond all emerging BIM definitions, the multifaceted nature of BIM is evident in the all proposed BIM frameworks in the peer reviewed literature. For example, the framework introduced by Taylor and Bernstein (2009) intended to recognising and investigating the "BIM use" models at the organisation level and their development from inside the firm into the supply chain showing the accumulative path starting from visualisation, coordination, analysing, and subsequently moving to BIM-based supply chain integration. Jung and Joo (2011) proposed a BIM framework aimed at determining the requirement of standard for process and product modelling and identifying three dimensions: 'BIM technology', 'BIM perspective' and 'construction business function'. These dimensions consolidate 'BIM technologies' (e.g., standards, property, relation, and utilisation) within various 'construction business functions' levels (i.e., project, organisation, and market perspectives). Another framework by Singh et al. (2011) which focuses on assessing and categorising the needs for BIM servers. It combines the BIM use (i.e., process) and BIM software platforms (i.e., technology). The proposed framework by Cerovsek (2011) recognises needs and suggestions for BIM schema development. It merges BIM processes (i.e., BIM use and interactions among project stakeholders) with technology (i.e., interoperability standard) using five standpoints (i.e., model, authoring tool, communicative intent, individual project task, and collaborative work). While the BIM framework developed by Succar (2009), which is relatively the most adopted one across the literature, it clearly demonstrates the multifaceted feature of BIM as it holistically portrays BIM knowledge domains and their interdependencies. BIM domains include 'BIM fields', 'BIM maturity stages' and 'BIM lenses'. Regarding BIM fields, they denote the domain key players (i.e., policy, technology and process). BIM maturity stages explain the development level of BIM implementation, and BIM lenses deliver particular layers of investigation that can be connected to both BIM fields and BIM maturity stages to create particular 'knowledge perspectives' (Succar, 2009) (Figure 2.1).

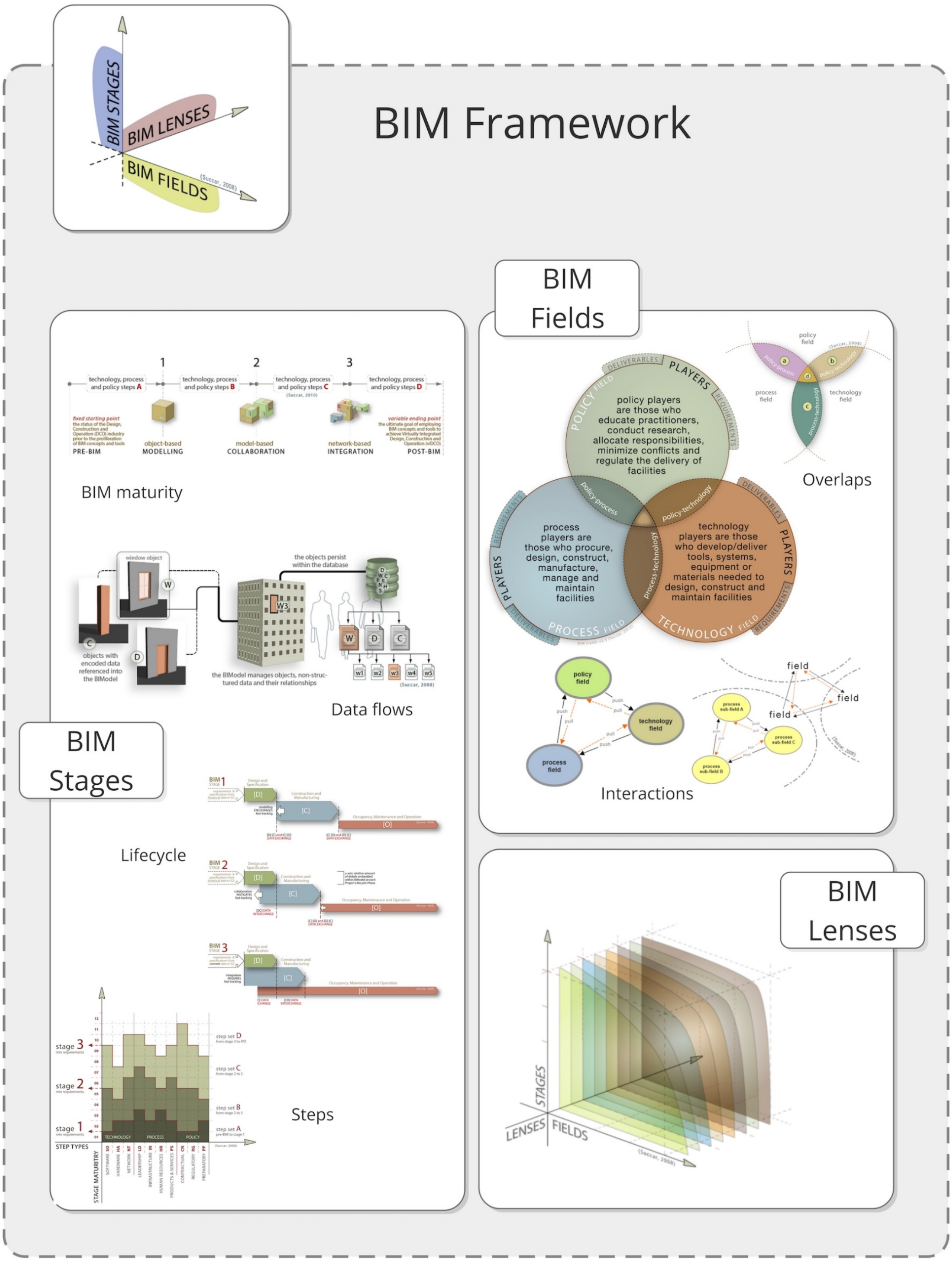


Figure 2.1 BIM Framework by Bilal Succar (adapted from Succar, 2009)

2.4 BIM policy, process and technology - UK National BIM initiative

For the purpose of providing evidence that BIM is a process and multifaceted innovation, this study will consider the UK as an example through demonstrating the UK Government Construction/BIM Strategy, its BIM Task Group, and the noteworthy documents and standards.

2.4.1 UK Government Construction/BIM Strategy

The emergence of BIM has been exceptionally obvious within the construction industry, and the UK Government BIM mandate came during the economic recession while the intentional and decisive organisational decisions of BIM adoption timing were impacted by negative and unfavourable predominant market considerations (Barry, 2016). In 2011, the UK Government declared the initiative of the four years Construction Strategy (Cabinet Office, 2011) aimed at reducing the expenditure of all public projects up to 20% by 2016. This strategy demands for "comprehensively changing the connection between the central government and the construction sector to attain the government objective and reaching its target that in turn offers the country, for the long-term, the needed financial and social foundation" (Cabinet Office, 2011).

The UK Government BIM mandate has been taken effect since April 2016. The mandate entails delivering all public assets, funded by the central government, via 'collaborative 3D BIM'. The BIM mandate is not enactment or the law in which the stakeholders (i.e., the design and construction teams) implement BIM, rather, utilising BIM represents a contractual requirement of working with the UK's leading client and central government (NBS, 2018).

2.4.2 The role of UK BIM Task Group

In 2011, the BIM Task Group was established as a steering time-limited task group. It is subsidised by the UK Government and led through the Cabinet Office (i.e., Government Construction Board) (Cabinet Office, 2011) to support delivering the

Government Construction Strategy goals and to broaden the capacity of the public sector of BIM implementation in order to meet its aim of the mandated adoption of collaborative Level 2 BIM in all its governmental buildings and departments by 2016. The BIM Task Group seeks to assemble various expertise from government, industry, institutes, public sector, and academia to help the supply chain achieving more efficient and collaborative working through a project and entire asset life cycle (BIM Task Group, 2014a). Its core BIM program has four principal working streams: *participant and media engagement, commercial and legal, delivery and efficiency, and training and academia, each task force led by a principal team member* (BIM Task Group, 2014c).

Based on its objectives, the BIM Task Group includes six main working parties/groups: COBie data set requirements, UK Contractors Group, Training and Education, Construction Products Association, BIM Technologies Alliance, and Plan of Works, (BIM Task Group, 2014d). Moreover, several BIM associations and groups (e.g. BIM4 Steering Group, BIM Regional Hubs, BIM4SMEs, etc.) that are all grouped under the BIM4 Communities of the official BIM Task Group (CIOB, 2014) (Figure 2.2).

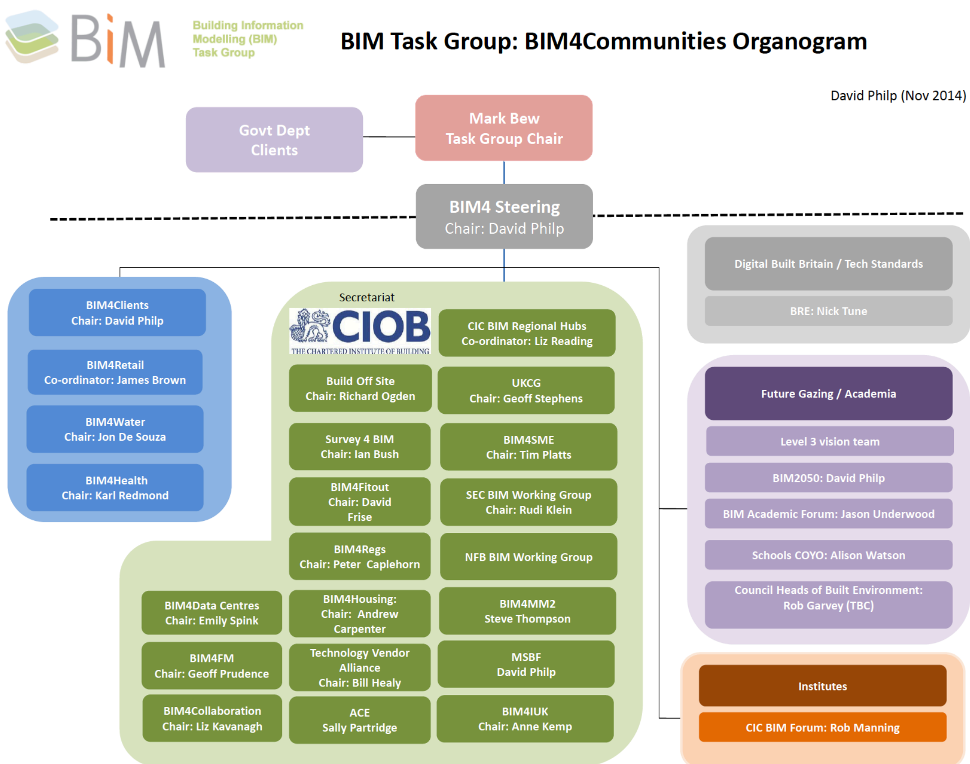


Figure 2.2 BIM Task Group: BIM4 Steering Group and BIM4 Communities in the UK (Philp, 2014)

2.4.3 The UK BIM noteworthy documents (Standards and Protocols)

In this section, the UK BIM documents and standards of the construction industry will be described. The 2011 published report of the Government Construction Client Group stating that to achieve the UK Government Construction Strategy, it is mandated for all the government construction work by companies tendering, should be matching level 2 BIM by 2016 (BIS, 2011). It defines Level 2 BIM as "*Handling 3D environment held in discrete discipline BIM tools with connected information* (BIM Task Group, 2014b) and the formation of model process standards and guidance within the asset whole lifecycle" (Reed, 2015). Moreover, later the report followed by the demarcation of ten noteworthy documents (Sands, 2014; Reed, 2015).These documents as following (Figure 2.3):

1. BS1192:2007 ("Collaborative production of architectural, engineering and construction information"): It is the fundamental document to the UK BIM processes that identifies the needed approach (Code of practice) to be undertaken of the collaboration processes among the project team for issuing data. Also, it offers a numbering framework layout so that records can be looked on electronic databases (BSI, 2007).

2. PAS1192-2:2013 ("Specification for information management for the capital/delivery phase of construction projects using building information modelling"): This document is based on the BS1192:2007. It characterises how the data is being managed across the process of the project construction phase. Also, it provides direction on the procedures required and prescribes the utilisation of the project information model (PIM) which includes BIM Execution Plan (BEP) and the Employers Information Requirements (EIRs) (i.e., the graphical, non-graphical documents and data) (BSI, 2013)

3. PAS1192-3:2014 ("Specification for information management for the operational phase of assets using building information modelling"): It is the companion document to the PAS1192-2:2013 except that it manages the asset operation phase (OPEX) and consequently the approach that how asset managers access the construction information and integrate the asset lifecycle data (BSI, 2014b).

4. BS1192-4:2014 ("Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice"): This code is the UK description of the Construction Operations Building Information Exchange (COBie) created in the USA and internationally utilised as a subset of Industry Foundation Class (IFC). It provides a global agreed approach between the owner and the supply chain for exchanging facility information (BSI, 2014a).

5. PAS1192-5:2015 ("Specification for security-minded building information modelling, digital built environments and smart asset management"): PAS 1192-5 stipulates and determines prerequisites for security management of BIM. It illustrates weaknesses in cybersecurity to hostile attack during implementing BIM and offers an evaluation procedure to decide the levels of cybersecurity for BIM collaboration within the building lifecycle. PAS 1192-5 proposes an applicable procedure across all built assets, which comprise all means of digital information (BSI, 2015).

6. The CIC BIM Protocol: It is a supplementary legal agreement (contract) that organises sharing the data among the stakeholders within a BIM-enabled project (CIC, 2013). This protocol aims to coordinate intellectual property rights provisions with the practical requirements of the BIM process that delineates how regularly the designs made by the consultants in the BIM process will be published and utilised (BIM Task Group, 2013).

7. Government Soft Landings (GSL) Policy: It is the UK Government policy in construction that ensures the soft transition of a built facility from the design and construction towards the operational phase. It is aligned with the values of the Post Occupancy Evaluation (POE) concept and Building Information Modelling (BIM) to compare the anticipated performance outcomes with the actual ones (Cabinet Office, 2013).

8. Classification (Structured and standardised information classification system): Uniclass 2 was created to produce a classification structure for organising data that is unreservedly accessible for all members during the project lifecycle and

afterward. It is dynamic, accessible online in different organisations and directed by a group of specialists who will screen demands, refresh and control forming. In the UK, the Unicalss 2 has been developed to facilitate the accuracy and readability of data by software systems to classify all parts of an asset (CPIc, 2015).

9. Digital Plan of Work (DPoW): it is the identified and requisite deliverables by the employer at each phase of the construction project (i.e., from the strategy development to operational and facility management). DPoW can enable the project members to comprehend their commitments and guarantee fitting deliverables of geometry, information and other documentation are set up for the client to allow opportune and effective decision making for the duration of the project lifecycle. The Digital Plan of Work can be developed by using the BIM Toolkit (NBS, 2017).

10. PAS1192-6:2018: This standard determines the requirements for collaborative sharing and the organised health and safety information when utilising BIM across the asset and project lifecycle. It can mitigate the corresponding risks, enhance the health and safety performance of the construction process, and decrease accidents related effects across asset lifecycle (BSI, 2018).

Moreover, there are still more upcoming BIM strategies standards and protocols are being developed globally and in the UK (Smith, 2014). Adopting and implementing the BIM/construction strategy and its pertinent standards and protocols entails enormous efforts by the potential adopters (e.g., the market, organisations, and individuals) in terms of the need for organisational restructuring to accept the new change; departing the conventional methods of working processes and procedures; investing in BIM technologies; providing a professional training; and accommodating with sharing risks and rewards contractual forms. Therefore, the aforementioned has confirmed both the disruptive and multifaceted aspects of adopting and implementing BIM innovation.

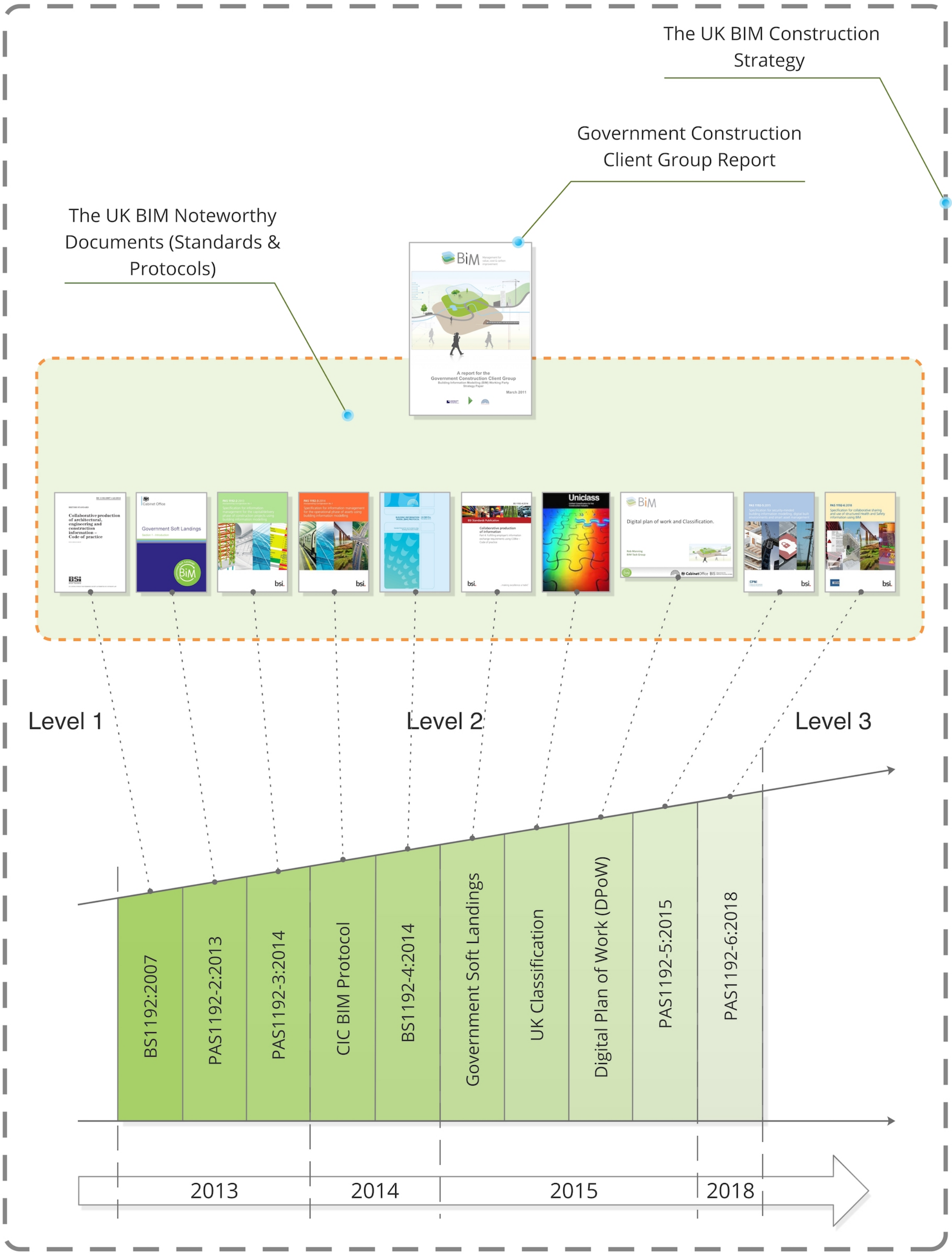


Figure 2.3 The UK BIM noteworthy documents (Standards and Protocols)

2.5 BIM diffusion (Awareness and adoption) and the need for Innovation adoption studies

Numerous industrial reports and academic studies have recurrently reported statistics regarding BIM awareness, adoption, and usage across multiple countries. Such noticeable industry reports encompass, for example: BIM diffusion in the U.S. and Canada; BIM diffusion in the UK (NBS, 2014; NBS, 2016; NBS, 2018); Autodesk software uptake in Europe (Autodesk, 2011); and The Business Value of BIM in Australia and New Zealand (McGraw Hill, 2014). Most of BIM adoption and implementation industry reports and surveys have increasingly thrived due to the lack of evidence-based approaches and non-appearance of researcher-driven investigations (Kassem et al., 2013). As discussed in Succar and Kassem (2015), despite the useful information included in these reports and surveys, several shortcomings have weakened them, as they: have anonymous or prejudiced data collection methodologies and population sampling; are unable to distinguish between real adoption and software attainments; lack of depending on a certain conceptual framework or proposing a new one; cannot be utilised by decision makers in encouraging BIM adoption; and generally disregard non-software features of BIM adoption (Fichman and Kemerer, 1999). On the other hand, in turn, the available academic BIM diffusion (adoption and implementation) studies have depended on the industry reports, which are commercially-led surveys ratings, as an input to initiate their research investigation grounds (Kassem and Succar, 2017). In general, there appears to be three identifiable patterns of BIM/innovation diffusion and adoption research in the existing literature: market-wide (Macro) studies (e.g., Cao et al., 2015; Takim et al., 2013; Xu et al., 2014), project-centric (Meso) studies (e.g., Cao et al., 2016; Juszczyk et al., 2015; London and Singh, 2013), and organisation-level (Micro) studies (e.g., Ahuja et al., 2016; Son et al., 2015; Rogers et al., 2015).

"At the macro market level, a number of studies have (1) identified the conceptual constructs of Macro-BIM adoption and proposed their use for assessing the maturity of whole markets (Succar and Kassem, 2015); (2) examined the financial and cultural issues related to BIM adoption across markets (Aranda-Mena and Wakefield, 2006);

(3) investigated the impediments to BIM adoption (Xu et al., 2014); (4) examined awareness of the technology among industry stakeholders (Abubakar et al., 2014); and (5) investigated the dynamics of BIM adoption within a specific markets (Seed, 2015)" (Ahmed and Kassem, 2018, p.103).

"Studies examining the BIM adoption at project level (i.e., Meso-level), have addressed (1) the changing relationships among project stakeholders and in particular the multi-disciplinary collaboration among them (Gu and London, 2010); and (2) BIM implementation motivations and the related project contextual factors (Cao et al., 2016)" (Ahmed and Kassem, 2018, p.104).

"Investigating BIM adoption at the organisational level (Micro-level) has also attracted significant attention in recent years. Research has been focussed on three key areas: (a) understanding the process of BIM adoption and diffusion by proposing approaches for predicting BIM diffusion (Gledson, 2015) or investigating the diffusion phase that follows BIM adoption (Kim et al., 2015); (b) identifying the drivers and factors that affect BIM adoption (Waarts et al., 2002), and (c) investigating relationships between organisation characteristics (e.g., size, age, resources, etc.) and the inclination of organisations to adopt innovation (Oliveira et al., 2014) (as cited in Ahmed and Kassem, 2018)" (Ahmed and Kassem, 2018, p.104).

Although the available BIM innovation adoption studies offer extra rigorous facts and information than industry reports and surveys, besides providing precious insights into BIM diffusion rates, patterns, and trends, and factors and drivers impacting the process of BIM adoption within organisations, however, they provide marginal realistic assistance to policy-makers and decision-makers in evolving new BIM adoption policies.

A possible opportunity to improve "existing literature is to address the dispersion of BIM adoption drivers and factors and develop an appropriate theoretical construct that synthesises this important knowledge area. This warrants new research on BIM innovation adoption" (Ahmed and Kassem, 2018, p.104).

The provided evidence about the disruptive and multifaceted nature of BIM, as a process-policy-technology, from the existing definitions and National BIM initiative (i.e., UK National BIM initiative), and the identified shortcomings included in the available BIM adoption research, all justifies the need for a new innovation adoption research that is BIM specific.

2.6 Summary and Conclusion

In this chapter, the most prominent BIM definitions were demonstrated. The existing literature was reviewed to portraying the disruptive and multifaceted nature of BIM. The UK construction industry was considered as an example - through demonstrating the UK Government Construction/BIM Strategy, the role of its BIM Task Group, and the noteworthy documents and standards - proving BIM as process, policy, and technology. Finally, the BIM adoption industry reports and the available BIM adoption academic research were demonstrated and discussed including the key areas, shortcomings, and possible opportunity to improve existing literature by addressing the dispersion of BIM adoption drivers and factors and develop an appropriate theoretical construct that synthesises this important knowledge area.

"Together the provided evidence about the multifaceted nature of the BIM innovation and the identified shortcomings within the current literature on BIM adoption justify theneed for a new innovation adoption for BIM specific." (Ahmed and Kassem, 2018, p.104).

In the next chapter, a Systematic Literature Review will be carried out to identify "an extensive set of drivers and factors that influence the decision to adopt BIM by organisations; and the pertinent theoretical fundamentals and lenses for the conceptual model for that guide the empirical investigation of the BIM adoption process" (Ahmed and Kassem, 2018, p.104).

Chapter 3 | Identifying BIM Adoption drivers, factors and theoretical fundamentals and lenses: A Systematic Literature Review

3.1 Introduction

This chapter aims to achieve Objectives 1 of this study:

"*To Identify an extensive set of drivers and factors that influence the decision to adopt BIM by organisations, and the pertinent theoretical fundamentals and lenses*" (Ahmed and Kassem, 2018, p.105).

By achieving this objective, it will provide the theoretical prerequisites to develop "a Unified BIM Adoption Taxonomy and a conceptual model to empirically examine the process of BIM adoption within architectural organisations" (Ahmed and Kassem, 2018, p.103). This chapter comprises four main sections. First section describes the Systematic Literature Review (SLR). Second section demonstrates the SLR execution process and its pertinent stages. Third section involves performing the SLR including three phases: review planning, conducting the review, and reporting the review. Final section presents the SLR findings and discussion.

3.2 Systematic Literature Review (SLR)

This study will conduct a Systematic Literature Review (SLR) to reduce bias (systematic error), answer clear research questions, and carry out an exploratory examination to comprehend the causes for heterogeneity (variations in outcomes) among presumably similar studies. "Accumulating knowledge of several different but related research is one of the most efficient approaches" (Ahmed and Kassem, 2018, p.104) to achieve a solid review of a certain issue as the outcome of a single study is not adequate to generalise on a specific issue (Abdul Hameed, 2012). To achieve an inclusive contribution to knowledge, outcomes of numerous studies can be combined to produce overall findings. As such, accumulating the previous literature on a certain subject provides clarification of the discrepancy which might occur among the primary studies, and validation of existing research findings (King and He, 2005). It is essential to summarise the outcomes from related studies by standardising their findings in the form, which enables comparisons through studies.

Investigating a particular issue by aggregating of information from the existing literature is recognised as a 'systematic literature review' (Abdul Hameed, 2012). Gomm (2008) uses the term 'Systematic Review' referring to a research review in which a standardised method is followed to collect information. For Fink (2013), SLR indicates - by a systematic - to the clear and reproducible approach for collecting and consolidating existent research knowledge. Similarly, Petticrew and Roberts (2006, p. 9) describe SLR as "*literature reviews that adhere closely to a set of scientific methods that explicitly aim to limit systematic error (bias), mainly by attempting to identify, appraise and synthesize all relevant studies to answer a particular question (or set of questions)*". The SLR is aimed at finding a precise conclusion of a particular problem and paving the path for future work (Ellis, 2010).

In the course of SLRs, evident and accurate methods are included to critically evaluate and synthesise relevant research studies (Sutton, 2000). Also, it is a reviewing procedure by which systematic decreases biases (Petitti, 1999). Implementing the methods of SLR helps in mapping out research extents of uncertainty "to recognise gaps and suggest opportunities for future research (Petticrew and Roberts, 2006)" (Ahmed and Kassem, 2018, p.104). Cooper et al. (2009) suggest four focusing areas of SLR. These are (1) drawing together the outcomes of individual studies; (2) recognising approaches utilised to undertake the research, (3) identifying the applicable theoretical lenses that were adopted to clarify the phenomena; and (4) investigating the applications or conducts performed to examine the facts.

In addition, Gomm (2008) designates five aspects in which a SLR may include: (1) studies which address similar research question; (2) an inclusive collection of both the published and unpublished studies to give reason for the research findings that resulted in both significant and insignificant findings; (3) the use of inclusion and exclusion criteria to eliminate the less quality studies through study selection phase;

(4) delineating outcomes from the total chosen studies; and finally (5) a statistical analysis might be performed to evaluate the overall finding (Abdul Hameed, 2012).

3.3 SLR execution process

Kitchenham and Charters (2007) identify "*planning, execution,* and *reporting results* as the three main *phases* of a systematic literature review" (Ahmed and Kassem, 2018, p.105). Tranfield et al. (2003) and Denyer and Tranfield (2009) provides well-defined *stages* of the SLR protocol: (1) formulation the review question, (2) locating studies, (3) study selection and evaluation, (4) analysis and synthesis, and finally (5) reporting the results. This five-step systematic or evidence-informed approach holds the main steps to counteract bias and to avoid the likelihood of possible distortions in the research and data analysis (Kamal and Irani, 2014). Similarly, Cook et al. (1997) and Chee et al. (2012) developed frameworks which represent a guidance to perform a systematic review that encompasses: searching process, studies selection, critical evaluation, and synthesis of primary research results.

3.4 Performing the SLR

To perform the SLR, this study will involve pre-defined and discrete activities, which can be grouped into three main stages which are designated by Kitchenham and Charters (2007): review planning, conducting the review, and reporting the review.

3.4.1 Phase I- Review process planning

This stage will encompass formulating the review/research questions and developing the SLR protocol to be executed in the next stage (i.e. conducting review process).

3.4.1.1 Developing the review protocol (SLR protocol)

During the planning phase of this SLR, the review protocol was developed following the pre-defined stages by Kitchenham and Charters (2007) and Tranfield et al. (2003) which mainly includes: identifying research questions, designing search strategy, study selection, quality assessment, data extraction, and data synthesis.

The first stage involved the articulating set of research questions depending on the SLR aims. Then, based on the research questions, the second stage encompassed designing search strategy to identify relevant studies regarding the research questions by specifying the search terms and the literature resources, which are essential to embark the subsequent searching processes. The third stage included identifying the criteria of study selection by which the relevant studies allowed addressing the SLR research questions. A pilot study selection was performed, in this stage, to achieve further refinement to selection criteria. Next, a quality checklist was devised where the relevant studies subjected to a quality assessment process. Once the studies have been decided upon, the residual two stages engaged "data extraction and data synthesis, respectively. In the data extraction stage, cards were devised into a form of table to enable data extraction, which was later refined by pilot data extraction" (Ahmed and Kassem, 2018, p.105). Finally, evidence that answers the research questions was aggregated from the selected studies by determining the proper methodologies in the data synthesis stage.

3.4.1.2 Identifying the research/review questions

The nature of the current systematic review is an exploratory study. It aims at understanding "the drivers and factors that influence organisation decisions to adopt BIM" (Ahmed and Kassem, 2018, p.103), and identifying the potential effect or impact of policy-makers' actions on their decisions (Ahmed et al., 2017). Formulating a clear research question is crucial to keep the direction and focus for any research. Hence, a key step in the SLR process is to formulate a set of research questions (RQs) (Kitchenham and Charters, 2007) to enable the extraction of data that is relevant to this aim. The subsequent RQs were used to guide data extractions:

- **RQ1–** "What are the drivers and factors affecting the decision to adopt BIM at organisation level within the construction industry?" (Ahmed and Kassem, 2018, p.106); and
- **RQ2**– "What are the theories, frameworks, and models adopted by scholars when examining BIM/innovation adoption and diffusion in construction?" (Ahmed and Kassem, 2018, p.106)

3.4.2 Phase II- Review process conducting

This section includes these stages: Search strategy, study selection criteria, quality assessment, data extraction, and data synthesis and analysis.

3.4.2.1 Search strategy

This stage had the two following steps:

Identifying search terms

To identify the search terms, the following steps were applied:

1. The research questions were broken down into key terms to derive the search terms based on the research aims by formulating a tentative title "BIM Adoption/Diffusion Drivers in the Construction Industry" and developing a search structural outline of IPDC (Innovation + Process + Determinant + Context) (Table 3.1 and Table 3.1).

2. Identifying alternative synonyms and spellings for the search key terms to make sure that all relevant records are retrieved. For instance, searching for 'Building Information Modelling', it would be prudent to search for the term 'BIM'. Also, searching for 'construction industry' might require searching the terms 'AEC', 'market', 'SMEs', 'firms', 'organisation', and 'practices' (Table 3.1 and Table 3.2).

3. Boolean operators such as 'OR' that was used to link alternative spellings and synonyms and 'AND' to connect the search key terms, were used to construct the search string. Hence, two search strings were formulated (Table 3.3).

Table 3.1 BIM Search Terms

Innovation	Process	Determinant	Context
Building Information Modelling	Adoption	Factor	Organisation
BIM	Implementation	Driver	Institution
Innovation	Diffusion	Behaviour	Firm
	Uptake	Pressure	SMEs
	Dynamic	Internal pressures	Market
	Top-down	External pressure	Industry
	Middle-out	Determinant	Country
	Bottom-up	Isomorphism	AEC
		Isomorphic	Construction industry
		Isomorphic pressure	UK
		Coercive	Macro
		Mimetic	Micro
		Normative	Meso
		Mandate	
		Decision-making	
		Policy-makers	

Table 3.2 Information Systems Search Terms

Innovation	Process	Determinant	Context
Information systems	Adoption	Factor	Organisation
IS	Implementation	Driver	Institution
Information Technology	Diffusion	Behaviour	Firm
IT	Uptake	Pressure	SMEs
ICT	Dynamic	Internal pressures	Market
Large scale technology	Top-down	External pressure	Industry
Innovation	Middle-out	Determinant	Country
Executive information system	Bottom-up	Isomorphism	AEC
ERP		Isomorphic	Construction industry
ERP2		Isomorphic pressure	UK
		Coercive	Macro
		Mimetic	Micro
		Normative	Meso
		Mandate	
		Decision-making	
		Policy-makers	

Table 3.3 SLR Booleans and search terms

ID	Search string
First search string (BIM)	(TITLE-ABS-KEY (**bim**) OR TITLE-ABS-KEY ([**Building Information Modelling**]) AND TITLE-ABS-KEY (**adoption**) OR TITLE-ABS-KEY (**implementation**) OR TITLE-ABS-KEY **(diffusion**) AND TITLE-ABS-KEY ([**construction industry**]) OR TITLE-ABS-KEY **(factor)** OR TITLE-ABS-KEY **(macro**) OR TITLE-ABS-KEY (**micro**) OR TITLE-ABS-KEY (**market**) OR TITLE-ABS-KEY (**country**) OR TITLE-ABS-KEY (**uk**) OR TITLE-ABS-KEY (**firm**) OR TITLE-ABS-KEY (**organisation**) OR TITLE-ABS-KEY (**institution**) OR TITLE-ABS-KEY (**aec**) OR TITLE-ABS-KEY (**sme**) AND TITLE-ABS-KEY (**isomorphic**) OR TITLE-ABS-KEY ([**isomorphic pressures**]) OR TITLE-ABS-KEY (**pressure**) OR TITLE-ABS-KEY (**driver**) OR TITLE-ABS-KEY (**internal**) OR TITLE-ABS-KEY (**external**) OR TITLE-ABS-KEY (**coerc***) OR TITLE-ABS-KEY (**mimet***) OR TITLE-ABS-KEY (**normative**) OR TITLE-ABS-KEY ([**decision making**]) OR TITLE-ABS-KEY (**policy**) OR TITLE-ABS-KEY (**behaviour**))
Second search string (Information Systems)	(TITLE-ABS-KEY ([**Information systems**]) OR TITLE-ABS-KEY (**IS**) OR ([Executive information system]) OR ([**Large scale technology**]) OR TITLE-ABS-KEY (**IT**) OR TITLE-ABS-KEY (**ICT**) OR TITLE-ABS-KEY (**ERP**) OR TITLE-ABS-KEY (**ERP2**) AND TITLE-ABS-KEY (**adoption**) OR TITLE-ABS-KEY (**implementation**) OR TITLE-ABS-KEY **(diffusion**) AND TITLE-ABS-KEY ([**construction industry**]) OR TITLE-ABS-KEY **(factor)** OR TITLE-ABS-KEY **(macro**) OR TITLE-ABS-KEY (**micro**) OR TITLE-ABS-KEY (**market**) OR TITLE-ABS-KEY (**country**) OR TITLE-ABS-KEY (**uk**) OR TITLE-ABS-KEY (**firm**) OR TITLE-ABS-KEY (**organisation**) OR TITLE-ABS-KEY (**institution**) OR TITLE-ABS-KEY (**aec**) OR TITLE-ABS-KEY (**sme**) AND TITLE-ABS-KEY (**isomorphic**) OR TITLE-ABS-KEY ([**isomorphic pressures**]) OR TITLE-ABS-KEY (**pressure**) OR TITLE-ABS-KEY (**driver**) OR TITLE-ABS-KEY (**internal**) OR TITLE-ABS-KEY (**external**) OR TITLE-ABS-KEY (**coerc***) OR TITLE-ABS-KEY (**mimet***) OR TITLE-ABS-KEY (**normative**) OR TITLE-ABS-KEY ([**decision making**]) OR TITLE-ABS-KEY (**policy**) OR TITLE-ABS-KEY (**behaviour**))

Literature resources

The online electronic databases were the main sources of data for the literature reviews. The used databases, that are specialised in construction, engineering and information systems, included: *Scopus* as it holds a wide range of up-to-date peer-reviewed journals and host a multidisciplinary research platform; *Science Direct*, and other individual databases such as *Ethos* (searching for PhD thesis) and *Google Scholar*. Search strings were adjusted to follow the interface requirements of each online database while holding the consistency of their logical order. While this review did not apply a timespan limit for the publications' search, the search results showed that the '*information systems*' topics started since the early 2000s and the '*Building Information Modelling*' topics started in late 2000s and spanned until May 2019 when this review has been conducted (i.e., 2000-2019).

3.4.2.2 Study selection criteria

Having applied the search strings, the obtained results were checked for suitability against two sets of pre-defined inclusion and exclusion criteria. Papers that were successfully passed the inclusion filter were sent forward the quality assessment stage, while the rejected ones, were excluded. These criteria as following:

Inclusion criteria:

- "Academic journal articles or conference proceedings papers with high methodological standards;
- English language material;
- Primary studies which are related to the research questions and the aim; and
- Studies that have reported the use of theories or developing frameworks and models to investigate BIM adoption process or innovation adoption process (i.e. BIM specific studies, construction industry, or information systems studies)" (Ahmed and Kassem, 2018, p.116).

Exclusion criteria:

- Studies published in languages other than English;
- Studies that are totally irrelevant to the main theme (i.e., the aim and the research questions);
- Studies that are out of the scope of innovation adoption/diffusion within an industry (i.e., not related to the construction industry, BIM and information systems and information technology);
- Duplicate materials (i.e., same studies that resulted from the application of different search string or retrieved from different online databases);
- Studies that are not following an empirical research method; and
- Master dissertations, books chapters, conference review, prefaces and opinions" (Ahmed and Kassem, 2018, p.116).

3.4.2.3 Quality assessment

The papers that successfully passed the inclusion filters were subjected to the quality assessment (QA) process. A quality checklist was devised based on combining both the SLR standard evaluation criteria of Cranfield University [cited in (Chee et al., 2012)] and the Database of Abstracts of Reviews of Effects (DARE) criteria of York University (Centre for Reviews and Dissemination, 2009), reaching to the final quality assessment (QA) questions:

- **"QA1**. Contribution: Does this paper add a contribution to the body of knowledge?
- **QA2**. Theory: Does the paper present an adequate literature review of the study domain including the underpinning theory?
- **QA3**. Methodology: Does the paper show a clear explanation of the methodology that can guarantee its replicability?
- **QA4**. Analysis: Does the paper have adequate data sample and its results support theoretical arguments with adequate explanations?" (Ahmed and Kassem, 2018, p.116).

Three optional answers were identified for each question: "Y (Yes)", "P (Partly)", or "N (No)". The score of these answers was: "Y= 1", "P= 0.5", "N= 0" or not applicable. The accepted paper had to meet the quality assessment criteria of at least one "Yes" with a maximum of one "No" out of the four QA questions by summing up the scores of the answers. The use of the quality assessment (QA) is generally for the purpose of weighting the resultant quantitative data in meta-analysis as a strategy for data synthesising (Higgins and Green, 2011). In this study the quality assessment scores were not used for this purpose as the resultant data were constructed by various empirical research designs and have a generally small amount of data which is inadequate for meta-analysis. Therefore, the results from applying the quality assessment criteria were exploited to guide the understanding of the SLR findings and signal the power of conclusions. Finally, the quality assessment process and its criteria provided an additional filter for study selection (Table 3.4).

3.4.2.4 Data extraction

37 papers successfully passed the quality assessment stage and moved onto the data extraction stage. The data of each study was extracted using a card that consists of three main parts are: "Publication demographic information (title, authors, publishing body, journal/conference, publishing year, and country of the study); Context description (Innovation topic area BIM/IT/IS adoption, innovation adoption level in terms of macro/meso/micro, data collection method, analysis method, research design, applied/adopted theories, frameworks, processes, and models attributed to BIM/innovation); and Findings (Identified drivers and factors influencing BIM/innovation adoption) (Cruzes and Dybå, 2011). Table A.1 (in Appendix A) is an example of the information extraction card" (Ahmed and Kassem, 2018, p.116). Then, each paper was evaluated against the predefined set of the two research questions (RQs), mentioned in Section (3.4.1.2 above, following the same scoring scale of the three optional answers, mentioned in Section (3.4.2.3) above, of "Y= 1", "P= 0.5", "N= 0".

3.4.2.5 Data synthesis and analysis

Once the data extraction process finished, the extracted data was transferred into Microsoft Excel software and synthesised in preparation for the analysis stage. Each paper was coded with a unique prefix tag (e.g., S1, S2, S3, etc.), as the letter "S" refers to "Study".

Subsequently, a *Descriptive statistical analysis* was performed as it suits the type of the extracted data and helps in illustrating the research questions (RQs) and clarifying the factors influencing BIM adoption in the construction industry. Tables and charts were also used to interpret the results and SLR final findings. The analysis was focussed on the research questions and linked with the seminal studies and theories on innovation diffusion. According to King and He (2005), there are four approaches for analysing the SLRs: descriptive review, narrative review, meta-analysis, and vote-counting. The descriptive and the narrative review are qualitative approaches that entail explanatory analysis of past studies and do not have pre-defined standard methods for analysis

(Hunter et al., 1982). In this study, the descriptive statistical analysis technique was employed as the resultant studies: (1) come from a number of domains (i.e. BIM adoption studies, IT/IS adoption, and generic innovation adoption in other industries); (2) are heterogeneous in interpreting the organisational behaviours against the BIM adoption process (i.e. organisational/individual level and dynamics, stages, and pressures), and (3) are constructed by various empirical research designs and have generally small amount of data which make them inadequate for meta-analysis.

In order to address the two research questions, the author employed various strategies to synthesise the extracted data related to each of the *RQs* as follows:

For ***RQ1***, the papers were examined to extract the drivers and factors that influence adoption decisions and identify the most common ones across all studies. As the number of studies focussed solely on BIM adoption is limited, studies addressing innovation diffusion in construction and information systems were included. The determinant factors include both the internal (intra-firm) and the external pressures (external isomorphic pressures) that are reported in studies' findings. These were then grouped under specific clusters of main drivers from RQ1.

For ***RQ2***, all the utilised theories, frameworks, and models used in the identified paper to examine BIM/innovation adoption were identified and the most applicable ones to the current research were reported.

To facilitate the analysis process, the aspects of the two research questions were tabulated, synthesised and depicted in (Table 3.5).

3.4.3 Phase III- Reporting the review results

This section includes summarising and reporting the results of this SLR.

3.4.3.1 SLR execution result reporting

Once the two search strings were executed, a total of 3110 papers were retrieved "(i.e., 1084, 693, 1330, and 3 for Scopus, ScienceDirect, Google Scholar and Ethos, respectively) for the primary search as stage one" (Ahmed and Kassem, 2018, p.105). These papers were exported to EndNote X7 software to perform the duplicate filter as stage two, which resulted in 398 papers. In stage three, after screening the titles of the papers to filter the totally irrelevant papers, 147 studies remained. Two software toolkits (i.e., online platforms) were used to implement the inclusion/exclusion criteria and to organise/categorise the SLR included records in the form that produces manageable outcomes for the data extraction to achieve the SLR aim. These online platforms are: (1) Rayyan QCRI[a] (Rayyan QCRI, 2016), and (2) Covidence[b] (Covidence, 2016). Both toolkits were separately used to double check the precision of the SLR outcomes. After applying the inclusion/exclusion criteria, stage four ended with 71 studies. Out of 71, 11 papers were also excluded due to full text missing. In the last stage, the residual studies (i.e. 60) were subjected to a quality assessment checklist that resulted in excluding 23 papers, which did meet the QA criteria. The 37 papers that passed all the stages were sent to the data extraction stage. Figure 3.1 shows the SLR execution process.

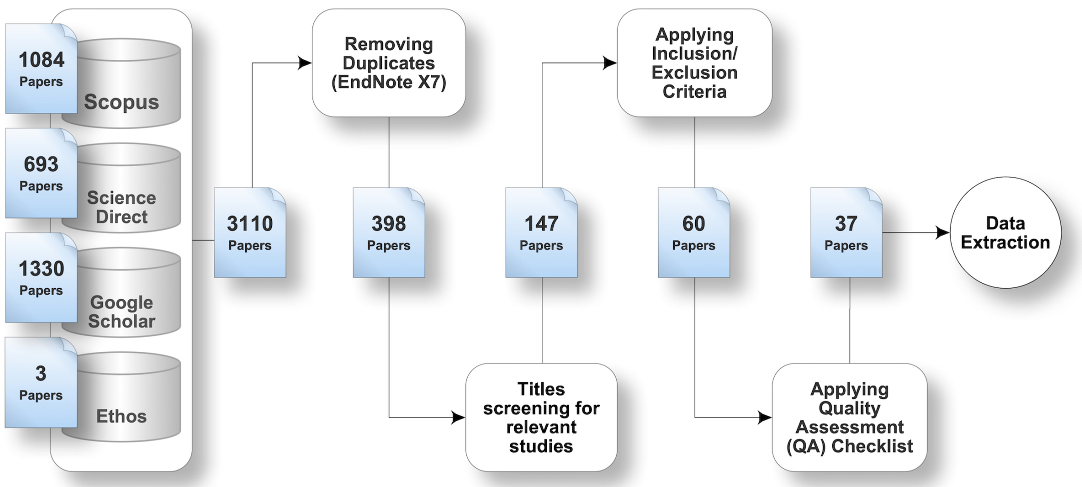


Figure 3.1 The SLR execution process

[a] Rayyan QCRI: a web-based application enables conducting a systematic review,https://rayyan.qcri.org/welcome
[b] Covidence: Cochrane's review production toolkit, https://www.covidence.org/home

3.4.3.2 Reporting the SLR data extraction results and discussion

This section analyses and discusses the outcomes of the systematic review. The first part provides a synthesis of the data and the second part discusses the outcomes considering the two research questions.

The results for the first part of the 37 papers are summarised including: 22 (59%) papers address the field of BIM adoption whereas the remaining 15 (41%) are focussed on the field of Information Technology (IT) or Information Systems (IS). Innovation adoption was discussed at three levels of organisational scales: Micro-level in 22 (59%) papers, Macro-level in 9 (25%) studies, and Meso-level in 6 (16%). The overall score from the quality assessment (QA) of all papers is 89% and it is considered very high. 18 (49%) papers scored 4/4 (100%).

With regards to the research methods and tools utilised in the identified papers, survey-based approaches were used in 88% of the studies. Case study and literature review were used in 6% of the studies each. The survey-based approaches consisted of questionnaires in 22 (59%) papers which make it the most frequent data collection method used in the identified studies. Other data collection methods such as mixed-methods, case study, literature review, and focus group interviews were used in 10 (29%), 2 (5%), 2 (5%), 1 (3%), respectively. 81% of the papers used quantitative statistical analysis while other methods including qualitative content analysis, mixed-methods, and narrative analysis were used in 15%, 3%, and, 3% of the studies, respectively.

Table 3.4 Scores from the quality assessment for the selected papers

Study ID	Author(s)	QA1	QA2	QA3	QA4	QA Score	QA %
S1	(Aranda-Mena and Wakefield, 2006)	P	P	Y	Y	3	75%
S2	(Cao et al., 2015)	P	P	Y	Y	3	75%
S3	(Gu and London, 2010)	Y	Y	Y	Y	4	100%
S4	(Xu et al., 2014)	Y	Y	Y	Y	4	100%
S5	(Rogers et al., 2015)	Y	P	Y	Y	3.5	88%
S6	(Kim et al., 2015)	Y	Y	Y	Y	4	100%
S7	(Takim et al., 2013)	P	P	Y	P	2.5	63%
S8	(Abubakar et al., 2014)	P	N	Y	Y	2.5	63%
S9	(Mom et al., 2014)	Y	P	Y	Y	3.5	88%
S10	(Cao et al., 2014)	Y	Y	Y	Y	4	100%
S11	(London and Singh, 2013)	P	Y	P	P	2.5	63%
S12	(Succar and Kassem, 2015)	Y	Y	Y	Y	4	100%
S13	(Singh and Holmstrom, 2015)	Y	Y	Y	P	3.5	88%
S14	(Ramanayaka and Venkatachalam, 2015)	P	Y	P	P	2.5	63%
S15	(Juszczyk et al., 2015)	P	N	Y	Y	2.5	63%
S16	(Son et al., 2015)	Y	Y	Y	Y	4	100%
S17	(Seed, 2015)	Y	Y	Y	Y	4	100%
S18	(Waarts et al., 2002)	Y	Y	Y	Y	4	100%
S19	(Sherer et al., 2016)	Y	Y	Y	Y	4	100%
S20	(Wu and Chen, 2014)	Y	Y	Y	Y	4	100%
S21	(Damanpour and Gopalakrishnan, 2001)	P	Y	Y	Y	3.5	88%
S22	(Shim et al., 2009)	P	P	P	P	2	50%
S23	(Yitmen, 2007)	P	N	P	Y	2	50%
S24	(Peansupap and Walker, 2005a)	Y	Y	Y	Y	4	100%
S25	(Talukder, 2012)	Y	P	Y	Y	3.5	88%
S26	(Hameed et al., 2012)	Y	Y	Y	Y	4	100%
S27	(Tsai et al., 2013)	Y	Y	Y	Y	4	100%
S28	(Oliveira et al., 2014)	Y	Y	Y	Y	4	100%
S29	(Henderson et al., 2012)	Y	Y	Y	Y	4	100%
S30	(Fareed et al., 2015)	Y	Y	Y	Y	4	100%
S31	(Tsai et al., 2010)	P	P	Y	Y	3	75%
S32	(Liu et al., 2010a)	Y	P	Y	Y	3.5	88%
S33	(Cao et al., 2016)	Y	P	Y	Y	3.5	88%
S34	(Ahuja et al., 2016)	Y	Y	Y	Y	4	100%
S35	(Gledson and Greenwood, 2017)	P	Y	Y	Y	3	75%
S36	(Hochscheid and Halin, 2018)	P	Y	Y	Y	3	75%
S37	(Ma et al., 2019)	Y	Y	Y	Y	4	100%
Total		30.5	29	35	34.5	128	89%

Regarding the second part, the subsequent sections include a discussion of the findings about each of the research questions:

All the included 37 (100%) studies have either fully addressed **RQ1** question by achieving full score “Y” (i.e., S1, S2, S5, S8, S10, S15, S16, S18, S22, S23, S27, S28, S29, S31, S33, and S37) or partially “P” (i.e., S3, S4, S6, S7, S9, S11, S12, S13, S14, S17, S19, S20, S21, S24, S25, S26, S30, S32, S34, S35 and S36) resulting in an overall score of 71.6% (Ahmed and Kassem, 2018, p.105) (Table 3.5).

By addressing “***RQ1***, an extensive set of *drivers* and *factors* for BIM adoption is identified” (Ahmed and Kassem, 2018, p.106). In this context, *drivers* represent clusters of incentives and *factors* that contribute to a greater propensity of adopting an innovation. *Factors* - within a driver cluster - represent key determinants that influence positively or negatively the decision process of innovation adoption. The identified drivers can be grouped into three main categories:

- Innovation characteristics (i.e., innovation perceived attributes);
- “Internal environment characteristics (i.e., adopter or organisation readiness)” (Ahmed and Kassem, 2018, p.110); and
- External environment characteristics (isomorphic pressures) (Table 3.6).

The “*innovation characteristics* include factors such as relative advantages, compatibility, complexity, trialability, observability (Tsai et al., 2013; Rogers, 2003), perceived ease of use, and perceived usefulness (Ramanayaka and Venkatachalam, 2015). The *internal environment characteristics* include factors such as organisational culture, firm size, top management support, client/owner willingness to change (Cao et al., 2014; Peansupap and Walker, 2005a; Tsai et al., 2010). The *external environment characteristics* include coercive pressures, mimetic pressures, normative pressures (Fareed et al., 2015; Henderson et al., 2012; Liu et al., 2010a; Shim et al., 2009), and competitive pressures (Oliveira et al., 2014; Yitmen, 2007)” (Ahmed and Kassem, 2018, p.106). Table 3.7, Table 3.8, and Table 3.9 present exhaustive lists of the key factors and determinants influencing the decision to adopt BIM/ innovation.

Table 3.5 The results of the selected studies (Demographic information, their research questions, and targeted scale)

Study ID	Author(s)	RQ1	RQ2	RQ %	Targeted scale	Country
S1	(Aranda-Mena and Wakefield, 2006)	1	1	100%	market-wide	Australia
S2	(Cao et al., 2015)	1	0	50%	market-wide	China
S3	(Gu and London, 2010)	0.5	1	75%	project level	Australia
S4	(Xu et al., 2014)	0.5	1	75%	market-wide	China
S5	(Rogers et al., 2015)	1	0	50%	organisational level	Malaysia
S6	(Kim et al., 2015)	0.5	1	75%	market-wide	South Korea
S7	(Takim et al., 2013)	0.5	1	75%	organisational level	Malaysia
S8	(Abubakar et al., 2014)	1	0	50%	market-wide	Nigeria
S9	(Mom et al., 2014)	0.5	0.5	50%	organisational level	Taiwan
S10	(Cao et al., 2014)	1	1	100%	project level	China
S11	(London and Singh, 2013)	0.5	1	75%	supply chain/market-wide	Australia
S12	(Succar and Kassem, 2015)	0.5	0.5	50%	market-wide	Australia/UK
S13	(Singh and Holmstrom, 2015)	0.5	1	75%	organisational/project level	Finland/Australia
S14	(Ramanayaka and Venkatachalam, 2015)	0.5	1	75%	organisational/project level	South Africa
S15	(Juszczyk et al., 2015)	1	0	50%	project level	Poland/ Czech Republic
S16	(Son et al., 2015)	1	1	100%	organisational level	South Korea
S17	(Seed, 2015)	0.5	1	75%	market-wide	UK
S18	(Waarts et al., 2002)	1	1	100%	organisational level	Netherlands
S19	(Sherer et al., 2016)	0.5	1	75%	market-wide	US
S20	(Wu and Chen, 2014)	0.5	1	75%	organisational level	Taiwan
S21	(Damanpour and Gopalakrishnan, 2001)	0.5	1	75%	organisational level	US
S22	(Shim et al., 2009)	1	0	50%	organisational level	South Korea
S23	(Yitmen, 2007)	1	0	50%	organisational level	Cyprus
S24	(Peansupap and Walker, 2005a)	0.5	1	75%	organisational level	Australia
S25	(Talukder, 2012)	0.5	1	75%	organisational level	Australia
S26	(Hameed et al., 2012)	0.5	1	75%	organisational level	UK
S27	(Tsai et al., 2013)	1	1	100%	organisational level	Taiwan
S28	(Oliveira et al., 2014)	1	1	100%	organisational level	Portugal
S29	(Henderson et al., 2012)	1	1	100%	organisational level	US
S30	(Fareed et al., 2015)	0.5	1	75%	organisational level	US
S31	(Tsai et al., 2010)	1	1	100%	organisational level	Taiwan
S32	(Liu et al., 2010a)	0.5	1	75%	organisational level	China
S33	(Cao et al., 2016)	1	1	100%	project level	China
S34	(Ahuja et al., 2016)	0.5	1	75%	organisational level	India
S35	(Gledson and Greenwood, 2017)	0.5	1	75%	project level	UK
S36	(Hochscheid and Halin, 2018)	0.5	1	75%	project level	France
S37	(Ma et al., 2019)	1	1	100%	organisational level	China
Total		71.6%	81%	76.3%		

Table 3.6 The clusters of BIM adoption drivers across the identified studies

ID	Author(s)	Internal characteristics	External characteristics	Innovation characteristics
S1	(Aranda-Mena and Wakefield, 2006)	✓	✓	✓
S2	(Cao et al., 2015)	✓	✗	✓
S3	(Gu and London, 2010)	✓	✗	✓
S4	(Xu et al., 2014)	✓	✗	✓
S5	(Rogers et al., 2015)	✗	✓	✗
S6	(Kim et al., 2015)	✗	✓	✓
S7	(Takim et al., 2013)	✓	✓	✓
S8	(Abubakar et al., 2014)	✓	✗	✓
S9	(Mom et al., 2014)	✓	✓	✓
S10	(Cao et al., 2014)	✓	✓	✗
S11	(London and Singh, 2013)	✓	✓	✓
S12	(Succar and Kassem, 2015)	✓	✓	✓
S13	(Singh and Holmstrom, 2015)	✓	✓	✗
S14	(Ramanayaka and Venkatachalam, 2015)	✗	✓	✓
S15	(Juszczyk et al., 2015)	✓	✗	✗
S16	(Son et al., 2015)	✓	✓	✓
S17	(Seed, 2015)	✗	✓	✓
S18	(Waarts et al., 2002)	✓	✓	✓
S19	(Sherer et al., 2016)	✗	✓	✗
S20	(Wu and Chen, 2014)	✓	✗	✓
S21	(Damanpour and Gopalakrishnan, 2001)	✓	✗	✓
S22	(Shim et al., 2009)	✓	✓	✗
S23	(Yitmen, 2007)	✓	✓	✗
S24	(Peansupap and Walker, 2005a)	✓	✗	✓
S25	(Talukder, 2012)	✓	✗	✓
S26	(Hameed et al., 2012)	✓	✓	✓
S27	(Tsai et al., 2013)	✓	✓	✓
S28	(Oliveira et al., 2014)	✓	✓	✓
S29	(Henderson et al., 2012)	✓	✓	✓
S30	(Fareed et al., 2015)	✗	✓	✗
S31	(Tsai et al., 2010)	✓	✓	✓
S32	(Liu et al., 2010a)	✗	✓	✗
S33	(Cao et al., 2016)	✓	✓	✓
S34	(Ahuja et al., 2016)	✓	✓	✓
S35	(Gledson and Greenwood, 2017)	✗	✗	✓
S36	(Hochscheid and Halin, 2018)	✓	✓	✗
S37	(Ma et al., 2019)	✓	✗	✓
	Total percentage %	79%	70%	73%

Table 3.7 The Clusters of the BIM innovation Characteristics

No.	Adoption Drivers	Adoption Determinants
1	**Perceived Usefulness**	Improvement of job satisfaction
		Improvement of job outcomes
		Improvement of job productivity
		Usefulness of BIM in job roles
2	**Perceived Ease of Use**	Convenience of BIM operation
		Understanding of BIM interoperability and ability to implement BIM tools
		Ease of getting expected outcomes by BIM
		Personal recognition about ease of BIM operation
3	**Relative advantage**	Productivity improvement
		Overall advantage in BIM job roles compared to pre-BIM roles
		shortening job duration and schedule
		Improvement of task performance and speed
		Effective reduction of risks
		Increased effectiveness in quality control
		Cost reduction/saving in workflows
		Expense and maintenance cost
		Consolidation of marketing strategy
		Increase of product/deliverable security
4	**Compatibility**	Ease of concurrent implementation or incorporation into existing processes
		Applicability to existing processes without radical change
		Compatibility of BIM with job roles
		Compatibility of BIM with work style
5	**Complexity**	Expectation that works become easier with BIM
		Expectation of smoother work processes with BIM
		Ease of familiarizing with BIM tools and processes
		Simplification of collaboration processes within the organisation
		Customisation and compatibility challenge
		Harmonization between standards
6	**Trialability**	Possibility of testing BIM tools and workflows before confirming adoption
		Possibility of risk reduction from testing before adopting in practice
		Possibility of testing various BIM tools' features to verify effects on deliverables
7	**Observability**	Evidence of cost saving from use / profitability
		Communicability and outcome / benefit demonstrability
		Perceived risk (e.g. functional risk, physical risk, financial risk, social risk, psychological
8	**Technological** factors	Interoperability among software applications
		Compatibility among software applications
		Visualisation of design effects
		Supporting characteristics and features
		Information sharing capabilities

Table 3.8 The Cluster of the Internal Environment Characteristics

No.	Adoption Drivers	Adoption Determinants
1	**Top management support**	Senior management support (internal motivations to actively embrace innovative
		Level of bureaucracy in BIM adoption decision-making
		Corporate/project leadership style (democracy/autocracy)
		Centralization of adoption decisions
		CEO innovativeness, attitude and IT knowledge
		Managers tenure
		Managers age
		CEO involvement
		Managers educational level
2		Effectiveness of information flows (communication flows) within organisations

	Communication behaviour	Level of internationalization and demographic factors
		Availability and effectiveness of construction supply chain management
		Availability and effectiveness of procurement system (inbound logistics)
		Strength of relationships with other parties (clients, governments, labour unions)
		External integration
		Learning from external sources
		Increase of Design and Build procurement
		Integration of operation
		Involvement in collaborative Procurement methods
3	**Financial resources and Perceived cost**	Outsourcing
		Cost of implementation
		Financial resources of organisation
		Selection of approach for building BIM model using in-house resources or outsourcing
		Construction cost reduction
		Design change cost effectiveness
		Financial resources devoted to IT technologies
		Perceived cost
		Project-based economic motives
		Cross-project economic motives
4	**Organisational readiness**	Adopters' positive experiences and ability to adapt the technologies to successfully
		Professional BIM technology training
		Training and support
		Human capability/resources (retention of best people)
		Innovation readiness (e.g. organisational learning, IS infrastructure, and IT readiness)
		Technical competence of staff
		Technological capability of organisation
		Research and development capability of organisation
		Risks associated with bidding BIM projects (types, size, teams, locations)
		Availability and effectiveness of operations system (products and services)
		Availability and effectiveness of human resource/maintenance system (for keeping
		Availability and effectiveness of quality assurance mechanism
		Availability and effectiveness of marketing and sales system
		Availability and effectiveness of procurement system (inbound logistics)
		Availability and effectiveness of managerial system (e.g., administrative system)
		IT intensity and integration between functional areas of the company
		Prior experience
		Earliness of adoption
		Strategic planning
		Satisfaction with existing systems
		Degree of integration
5	**Social motivations**	Individual and group motivation for BIM adoption
		Need for process reengineering for BIM
		People resistance to BIM change
		Socioeconomic conditions
		Perceptions and attitudes
		Subjective norm
		Attitude towards the type of innovation (IT)
		Social influence (managers capture social pressure based on their perceptions rather
		Positive/negative feelings towards use
		Social network the organisation is involved in
		Availability of a product champion or a changed agent within the organisation
		Internal pressure from individuals and groups to adopt innovation
		Norm encouraging change
		Desirability of undertaking a championing image within the market (image motives)
		Catching up with adoption already happening within their clusters (Reactive motives)
6	**Organisational culture**	Enabling environment
		Organisational flexibility/adaptability to market
		Need for organisational restructuring
		Corporate management style (family owned or public owned)
		Internal process perspective
		Learning & growth perspective

		Supporting individual / personal characteristics
		Supporting open discussion environment
		Supervisor and organisational support
		Openness
		Control orientation
7	**Willingness**	Level of business interest
		Interest in learning BIM tools and workflows
		Need to change in organisation characteristics for BIM (i.e., types, size, structure,
		Need for innovation / diffusion of innovation
		Incentives for adoption
		Individual/adopter enjoyment with innovation
		Competitive advantages in market (core/unique competencies)
		Increased demand for BIM
		Willingness to use BIM by supply chain stakeholders
8	**Organisation structure and size**	Whole organisational structural complexity
		Organisation size
		Information system department size

Table 3.9 The Cluster of External Environment Characteristics

No.	Adoption Drivers	Adoption Determinants
1	**Coercive pressures/ forces**	Client's enthusiasm to adopt new technology
		Pressure from competitors and peer association within the market
		An Evident push from governments to expedite the BIM uptake
		Clients and owners support
		BIM mandate by either clients or Governments
		Government financial support and subsidy
		Regulation, policy & industry standards
		Clients' interest in the use of BIM in their projects
		Government support and policy through legislation
		Influence from partners who have already adopted BIM
		Formal and informal pressures exerted on organisations by other organisations
		Multi-disciplinary association pressures
		Dependence on parent adopting company
		Refusal to trade/deal with non-adopters
2	**Mimetic pressures/forces**	Mimicking behaviours by imitating successful practices/competitors in the market
		Mimetic isomorphism in IT platform migration
		Best practices for constructability implementation
		Industry associations' practice
		Main competitors' actions
		Industry IT/innovation competitiveness
		Competition among IT suppliers
3	**Normative pressures/ forces**	Availability of BIM professionals within the market
		Availability and affordability of BIM training
		Externalities that affect practitioners' attitudes
		Awareness of the technology among industry stakeholders
		Strength of culture (e.g., shared identity, norms, values, and assumptions)
		Shared norms and collective expectations diffused through information exchange
		Performance measures and benchmarking for continuous improvement
		Globalisation and competitive strategies
		Organisational culture and cultural changes among industry stakeholders
		Contractual sharing norms
		Proliferation of initiatives for change by government and professional bodies
		Pressure from public
		Industry associations' practice
		Trend of channel cooperation

31 (83%) studies were able to either address **RQ2** by achieving full score "Y" (i.e., S1, S3, S4, S6, S7, S10, S11, S13, S14, S16, S17, S18, S19, S20, S21, S24, S25, S26, S27, S28, S29, S30, S31, S32, S33, S34, S35, S36, and S37), or partially "P" (i.e., S9, and S12), whereas the 6 residual papers did not cover this aspect with zero score (i.e., "N"). Therefore, interestingly, these studies were able to provide 81% of the required information to answer this question (Table 3.5).

"Out of 37, 31 (83%) papers adopted theoretical standpoints to guide and analyse the process of BIM adoption/innovation adoption. The adopted theories included: Innovation Diffusion Theory (IDT), which has achieved the highest score at (57%). Then the Institutional Theory (INT) with (24%), while Technology Acceptance Model (TAM) and using mixed-theories are 21% each. Also, (6%) is for the Theory of Reasoned Action (TRA)" (Ahmed and Kassem, 2018, p.110) (Figure 3.2).

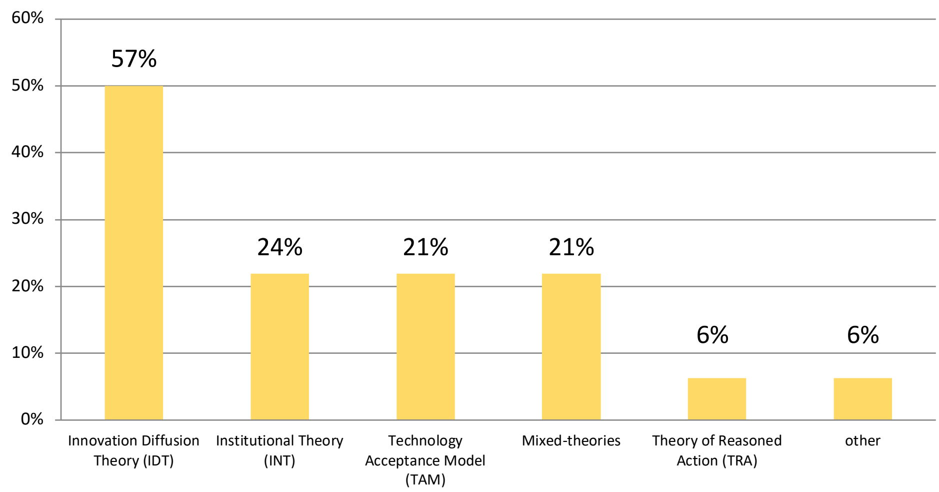


Figure 3.2 The Adopted Theories in SLR Studies

The Innovation Diffusion Theory (IDT) remains one of the most commonly applicable theories when investigating adoption by *individual* and *organisational*. It suggests five elements represent the '*innovation characteristics*', these are: "[(1) Relative advantage, which is "*the degree to which an innovation is perceived as being better than the idea it supersedes*" (Rogers, 2003, p. 229); (2) Compatibility, "*the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters*" (Rogers, 2003, p. 240); (3) Complexity, "*the degree to which an innovation is perceived as difficult to understand and use*"(Rogers, 2003, p.257); (4) Trialability, "*the degree to which an innovation can be experimented with on a limited basis*"; and (5) Observability, "the degree to which the results on an innovation are visible to others" (Rogers, 2003, p.258). Also, IDT presents the "*adopter characteristics*" (i.e., internal characteristics of individuals or the decision-making unit) in terms of: Socioeconomic characteristics, personality variables, and communication behaviour. Moreover, it categorises five types of *adopter*: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2003, p.282). In addition, IDT suggests a five-stage model of "*innovation-decision process*" by which an innovation adoption occurs through: awareness, interest, decision, implementation, and confirmation (Rogers, 2003, p.169)]" (Ahmed and Kassem, 2018, p.108). As IDT only interpret the behaviour of individuals when adoption a technological innovation, numerous studies have combined IDT with other theories to investigate and explain the adoption process and the implementation of IT innovation in organisations (Chwelos et al., 2001b; Mehrtens et al., 2001).

The Technology Acceptance Model (TAM), proposed by Fred Davis (1989), suggests that the use of a new system could be determined by two main factors: "[*perceived ease of use* (PEU) and *perceived usefulness*. It helps in establishing theoretical linkages among beliefs, intention, and action (Xu et al., 2014) to explain system use. Perceived usefulness is "*the degree to which a person believes that using a particular system will enhance his or her job performance*" and Perceived ease of use is "*the degree to which a person believes that using a particular system will be effortless*" (Davis, 1989, p.320). TAM proposes that user's belief (i.e. the PEU and PU) about a given system influences their behavioural intention to use, which in turn, determines the actual system use (Davis, 1989; Xu et al., 2014). Hence, TAM seeks to predict users' acceptance of a technological innovation and explain the behaviour of individuals against IT acceptance (Hameed et al., 2012)]" (Ahmed and Kassem, 2018, p.108).

The Institutional Theory (INT) developed by DiMaggio and Powell (1983) emphasise that "[institutional external isomorphic pressures motivate organisations to perform behavioural and structural changes aiming at acquiring social legitimacy. These institutional pressures are: coercive pressures, mimetic pressures, and normative pressures (DiMaggio and Powell, 1983; Fareed et al., 2015; Henderson et al., 2012). Coercive isomorphism emerges from political effect and legitimacy issues (DiMaggio and Powell, 1983). These effects might be formal and informal pressures applied on organisations by other organisations upon which they are dependent. Thus, the dependent organisations might manifest similar adoption aspects of the organisations they are dependent upon (Teo et al., 2003). These pressures could be sensed as forces, persuasion, or as offers to join in an alliance. Mimetic isomorphism emerges from competitive forces and may drive the organisation to equivalent adoption decisions as its successful peers (DiMaggio and Powell, 1983). Hence, mimetic pressures may exhibit two forms: either by imitating competitors who have achieved successful adoption of an innovation due to a high level of uncertainty that makes organisations imitate successful competitor which is called "social threshold" (Teo et al., 2003), or based on the rate of an innovation adoption in the industry where the organisation operates. As such, an organisation adopts an innovation to avoid the risk of being perceived as less innovative, when enough evidence is available of prior adopters finding it worth adopting (DiMaggio and Powell, 1983). This is called "social learning" that based the bandwagon effect (Son and Benbasat, 2007). While normative isomorphism stems from common norms and shared values and it is related to professionalization and relations with organisations (DiMaggio and Powell, 1983; Teo et al., 2003). Thus, organisations either to comply with formal pressures (mandates, regulations), mimic successful practices, or conform to informal restrictions (i.e., beliefs, norms, and conventions), and the institutional legitimacy will be determined considering the organisations' response towards these pressures]" (Ahmed and Kassem, 2018, p.108).

Depending on the results, it could be argued that there is, to some extent, a misemployment in a number of research that led to misconstrue regarding the terminologies, theoretical representation, and the intentional level of analysis of BIM adoption or IT/IS adoption. In terms of terminology misuse, numerous papers were excluded from this SLR since they used "adoption" instead of "implementation" to explain the use of either BIM implementation or IT/IS implementation that raises some conflicts, and misuse due to the interplay among the concepts of adoption, implementation, and diffusion. For theoretical representation, lots of papers employed certain theories (e.g., TAM) that initially proposed to explain the use of an innovation by individual members inside organisations to investigate the factors influence the *adoption* decision and the process of adoption (instead of implementation) regardless other crucial aspects (internal and external characteristics) at organisational level (e.g., S4, S6, S14, and S16). While regarding the intentional level of analysis adoption/diffusion, similarly, a number of papers sought to investigate a certain level (e.g., organisational level) but they applied either individual or project-based level characteristics.

Overall, there seems to be some evidence to indicate that the final 34 investigated papers lack the use of IDT and INT jointly in examining the factors influencing the organisation's behaviour to innovation-decision adoption, except 5 papers (i.e., S12, S27, S29, S33, and S34). Regarding paper (S12), it does not adopt IDT and INT; rather, it has harnessed them to clarify the conceptual constructs. While for papers (S27) and (S29), they have both depended heavily on INT attributes regarding "isomorphic pressures with a peripheral use of IDT aspects that lacks holistic adoption. Also, for papers (S33) and (S34), similarly both have only focused on limited aspects of IDT (i.e., control variables and economic motivations for S33, and BIM technology, top management support for S34) and INT (i.e., social motivations for S34, and client support and trading partner for S34) regardless other main aspects. Despite the use of IDT and INT in these papers, they lack to provide a clear understanding of the whole stages of the adoption process and" (Ahmed and Kassem, 2018, p.108) a holistic view of the potential factors influencing the decision to adopt (Table 3.10).

Table 3.10 Theories used to explain BIM and innovation adoption across the 37 studies

ID	Author	IDT	INT	TAM	IDT+TAM	IDT+INT	Other
S1	(Aranda-Mena and Wakefield, 2006)	•					
S2	(Cao et al., 2015)						
S3	(Gu and London, 2010)						
S4	(Xu et al., 2014)				•		
S5	(Rogers et al., 2015)						
S6	(Kim et al., 2015)				•		
S7	(Takim et al., 2013)			•			
S8	(Abubakar et al., 2014)						
S9	(Mom et al., 2014)						
S10	(Cao et al., 2014)		•				
S11	(London and Singh, 2013)	•					
S12	(Succar and Kassem, 2015)					•	
S13	(Singh and Holmstrom, 2015)	•					
S14	(Ramanayaka and Venkatachalam, 2015)			•			
S15	(Juszczyk et al., 2015)						
S16	(Son et al., 2015)			•			
S17	(Seed, 2015)	•					
S18	(Waarts et al., 2002)	•					
S19	(Sherer et al., 2016)		•				
S20	(Wu and Chen, 2014)	•					
S21	(Damanpour and Gopalakrishnan, 2001)	•					
S22	(Shim et al., 2009)						
S23	(Yitmen, 2007)						
S24	(Peansupap and Walker, 2005a)	•					
S25	(Talukder, 2012)			•			•
S26	(Hameed et al., 2012)				•		•
S27	(Tsai et al., 2013)					•	
S28	(Oliveira et al., 2014)	•					
S29	(Henderson et al., 2012)					•	
S30	(Fareed et al., 2015)		•				
S31	(Tsai et al., 2010)	•					
S32	(Liu et al., 2010a)		•				
S33	(Cao et al., 2016)					•	
S34	(Ahuja et al., 2016)					•	•
S35	(Gledson and Greenwood, 2017)	•					
S36	(Hochscheid and Halin, 2018)	•					
S37	(Ma et al., 2019)	•		•			•

3.5 The SLR findings

Given the results and their discussion of the SLR, the overall findings provided the author of this study with an adequate synthesis to further develop a body of proof regarding the key factors influencing the BIM adoption-decision and the process of adoption that were examined in this SLR. Hence, considering the results of this SLR, it provides the theoretical prerequisites to develop a "Unified BIM Adoption Taxonomy and a conceptual model" (Ahmed and Kassem, 2018, p.103) to empirically examine these aspects.

As this study aims at understanding the "*drivers* and *factors* that influence organisations' decision to adopt BIM" (Ahmed and Kassem, 2018, p.106), and identifying a potential equivalence with policy-makers' actions and adoption decisions, it will *retrospectively* examine how the adoption process initially occurred and what are the key factors influence the organisation's behaviour to BIM adoption decision. Accordingly, this study will propose a *taxonomy* and a *conceptual model* (in Chapter 5) based on the drivers and factors in the results section, which are: "*BIM innovation characteristics*, *Internal environment characteristics*, and *External environment characteristics*" (Ahmed and Kassem, 2018, p.108).

When the **BIM Innovation characteristics** are discussed, Building Information Modelling (BIM) should be conceived as a disruptive technology (Deutsch, 2011; Eastman et al., 2008a). It is an emerging innovation of procedural change and technological shift across the construction industry (Succar, 2009). BIM involves the change in both technology and process (Eastman et al., 2011). According to Succar (2009, P.357), BIM is an extensive domain of knowledge across the construction industry. BIM is identified as "boundless" (Harty, 2005, P.51) or a "systemic" innovation (Taylor and Levitt, 2004, P.84) that in opposite to localised innovation since it affects various professional organisations and its diffusion rate is slower than localised innovations (Taylor, 2007). Similarly, Damanpour and Gopalakrishnan (2001, p.48) identify two types of innovations: "product innovation" which is a "*new services or products introduced to meet an external user or market need*", and "process innovation" which is a "*new elements introduced into an organisation's production or service operations (e.g., input materials, task specifications, work and information flow mechanisms, and equipment) to produce a product or render a service*" (Utterback and Abernathy, 1975; Ettlie and Reza, 1992). In addition, product innovation has a marketplace attention with customer driven, whilst the process innovation has an organisational focus with efficiency-driven (Utterback and Abernathy, 1975), and the adoption of both is influenced by different factors which determine the degree to which the two innovations influence the adopting organisation (Tornatzky et al., 1990). Thus, BIM is more likely to be considered as a "process innovation".

Regarding the "**Internal environment characteristics**, and the **External environment characteristics**, this study will employ and combine both the Innovation Diffusion Theory (IDT) and the Institutional Theory (INT) as they complement the two aspects in a complementary way. Hence, IDT will provide the theoretical lenses for investigating the BIM characteristics (i.e., innovation attributes) and the organisation internal environment characteristics (i.e., adopter or organisation readiness), while INT will cover the external environment characteristics (i.e., institutional isomorphic pressures)" (Ahmed and Kassem, 2018, p.110).

A large number of growing literature has been published on the significant role of the institutional diffusion of IS/IT innovation in achieving the successful implementation and optimum performance of a firm (e.g., Ramamurthy et al., 1999; Santhanam and Hartono, 2003; Ranganathan et al., 2004; Zhu et al., 2006). The diffusion process is complicated and dynamic in nature and is affected by various sets of contextual attributes over time and leads to different manners/attitudes of organisational impacts (Prescott and Conger, 1995). It has been argued that a multi-stage diffusion analysis would deliver insight into understanding IS implementation issues with potential solutions rather than single-stage of this process (Gallivan, 2001). Given the multi-stage of the IDT which is initially identified for investigating how the process of the innovation diffusion is directed and affected by changes in related variables over a period of time, a model of two-stage, namely: adoption and implementation, was originally suggested by Rogers (1971) in his seminal work in 1962. He suggested a five-step decision-making process of innovation adoption: awareness, interest, evaluation, trial, and adoption. Then, he has modified these terminologies to: *knowledge, persuasion, decision, implementation*, and *confirmation* (Rogers, 2003).

In addition, a number of studies have further decomposed the ***adoption stage*** into: knowledge possession, persuasion and learning, and decision, reaching to the real adoption decision. The ***implementation stage*** categorised into: the innovation technology required for spreading, arrangements of transition in task structure, and task process (Wu and Chen, 2014). For instance, a two-stage model: *internal assimilation* and *external diffusion*, is required to understand the relation between the diffusion of the technologies of supply chain and the firm performance by

Ranganathan et al. (2004). Many researchers have similarly proposed a three-stage diffusion model (e.g., Grover and Goslar, 1993; Zhu et al., 2006; Wu and Chuang, 2010). The three-stage model of Grover and Goslar (1993) included: *Initiation, adoption,* and *implementation*. Similarly, Zhu et al. (2006) developed a diffusion model; initiation, adoption, and routinization, to investigate the uptake of e-business innovations in a firm. While the three-stage model proposed by Wu and Chuang (2010): *Earliness of adoption*, *routinization,* and *infusion*, were used to examine the diffusion of a supply chain technology. Also, Swanson and Ramiller (2004) applied a four-stage diffusion model: *Comprehension, adoption, implementation,* and *assimilation*, to explore the organisational role and involvement of a firm in IS innovation diffusion. A five-stage diffusion model suggested by Meyer and Goes (1988): *knowledge awareness, evaluation, adoption, implementation*, and *expansion*, used to examine organisational innovation diffusion. Finally, a study has proposed a six-stage model*: initiation, adoption, adaptation, acceptance, routinization,* and *infusion*, to investigate the effects of different contextual factors on the implementation of corporation resource planning systems (Rajagopal, 2002).

According to the results' findings, considering the diffusion process, the decision to adopt at early stages seems to be driven by a combination of *internal factors* and *attitudes* of the organisation (i.e., awareness and then intention) together with *external forces* (i.e., institutional isomorphic pressures). At a later stage, when the organisation reaches the point of adoption, another set of adoption-based combined factors tends to drive the diffusion process towards the implementation stage at individual (i.e., people/staff) level inside organisation.

3.6 Summary and Conclusion

In this chapter, a Systematic Literature Review (SLR) was conducted to identify an extensive set of drivers and factors that influence the decision to adopt BIM by organisations, and the pertinent theoretical fundamentals and lenses. Performing the SLR resulted in identifying set of three *driver* clusters including: "BIM innovation characteristics (i.e., innovation perceived attributes); Internal environment characteristics (i.e., adopter or organisation readiness); and External environment characteristics (isomorphic pressures)" (Ahmed and Kassem, 2018, p.110). Also, 19 *factors* were identified under the three driver clusters. These key factors expanded into a list of exhaustive *determinants* which demonstrate the different manifestations of each driver. Two pertinent theoretical fundamentals and lenses were identified including the Innovation Diffusion Theory (IDT) and Institutional Theory (INT). Furthermore, 81% of the papers used quantitative statistical analysis and the survey-based questionnaire was used in 56% of the papers, which makes it the most frequent data collection method used in the selected studies. Thus, this determined the selection of this study to adopt the quantitative approach for collecting and analysing the empirical data besides the quantifiable nature of the sought data. Hence, Objective 1 of this study is achieved.

Having achieved this objective, this chapter will inform Objective 2 (i.e., in Chapter 5) by providing the theoretical prerequisites to develop a Unified BIM Adoption Taxonomy and a conceptual model to empirically examine the process of BIM adoption within architectural organisations.

Chapter 4 | Research Design and Methodology

4.1 Introduction

The aim of this chapter is to provide an explanation of the methodological and philosophical choices that underpinned this research. This chapter identifies, discusses and illustrates the research types adopted; the research paradigms (i.e., ontological and epistemological positions); the research approach, strategy and methods; the research design and methods; and finally, the ethical considerations.

4.2 Research Purpose

In research methodologies, the purpose of the research is one of the perspectives of the types of research (Kumar, 2010). Types of research can be classified from the perspective of (1) 'research purpose' or 'objective' (e.g., descriptive, exploratory, explanatory, or correlational); (2) 'application' (e.g., applied research or pure research); (3) the employed 'enquiry approach' (e.g., quantitative or qualitative) (Kothari, 2004; Kumar, 2010); (4) the required time to accomplish study (i.e., cross-sectional research, longitudinal research, or one-time research) (Kothari, 2004; Bryman, 2012); and (5) the 'environment' where the study is conducted (e.g., laboratory experiment, field-setting research, or simulation research) (Kothari, 2004).

Research types are utilised to depict the fundamental characteristics underpinning given research. This includes the process of identifying key attributes that explain the research aim and objectives in a particular context. It also includes describing what can be anticipated from specific research. **Descriptive research** is portrayed as "*an efficient method to acquire data utilised in formulating hypotheses and proposing relationships*" (Monsen and Van Horn, 2007, p. 5). It aims to systematically explain a phenomenon, state, problem, service or delivers information about attitudes towards an issue, within a certain context (e.g., time, place, culture) (Kumar, 2010). Descriptive research cannot be employed to test and validate any study as it just describes the issue/problem under investigation. It firmly pertains with the qualitative approach, which is an interpretive and subjective essence. Thus, various researchers can illustrate similar studies using a wide range of methods relying upon the context of appropriate backgrounds (Monsen and Van Horn, 2007). **Exploratory research** is defined as a study that is carried out with the aim of either exploring an area or phenomenon that is little known or investigating the opportunities of conducting a particular research study (Kumar, 2010, p. 30). It concerns in developing hypotheses and generating theories rather than testing them (Kothari, 2004), and hence, it is more related to the qualitative approach (Bryman, 2012). **Explanatory Research**, which is also called causal research, seeks to explain the reasons (i.e., cause and effect) of why events occur and to construct, elaborate, broaden, or test hypotheses and theories (Neuman, 2013). It aims at elucidating 'why' and 'how' a relationship established between two aspects of a condition or phenomenon within a particular context (Kumar, 2010). Explanatory research develops a novel explanation and then presents empirical evidence to either support it or refute it. Usually, explanatory research expands on descriptive and exploratory research and proceeds on to recognise the reason something occurs (Neuman, 2013; Kothari, 2004). Ultimately, explanatory research has two main objectives: identifying and understanding which variables are the cause and which are the effect, and explaining the nature of the relationship between the cause and effect variables (Neuman, 2013). Researchers often rely on explanatory research in conducting studies adopt quantitative strategies (Bryman, 2012; Neuman, 2013). **Correlational research** can be defined as "a non-experimental approach" (Jackson, 2015) that identifies or establishes a relationship or interdependence between two or more variables (i.e., a naturally occurring variable which has not experienced any manipulation by the researcher) of a phenomenon (Kumar, 2010). It is based on comparing two or more studies as one study cannot be analysed using correlational research (Kumar, 2010; Jackson, 2015).

This study predominantly falls into the class of explanatory research and secondarily within descriptive research. As presented in the next chapters, the proposed conceptual model, which combined the Innovation Diffusion Theory with the Institutional Theory, was used to perform a multifaceted analysis of the BIM adoption process (i.e., hypotheses testing) to identify set of 11 most influencing factors on BIM adoption process, and to develop some of the conceptual constructs (i.e., two-dimensional characterisation model of BIM adoption, cause of effect diagraphs and causal loop diagrams). A descriptive statistical analysis was used in conducting the Systematic Literature Review (SLR) and in analysing and reporting some of the results of the survey questionnaire.

4.3 Research philosophy (Paradigm)

The research paradigm or philosophy is a pivotal prerequisite in undertaking research and eliciting substantial outcomes. A paradigm can be defined as "*a set of very general philosophical assumptions about the nature of the world (ontology) and how we can understand it (epistemology)*" (Maxwell, 2008, p.224). Various paradigms must be considered when it comes to designing the study methodology and approach. As indicated by Teddlie and Tashakkori (2010), paradigms are key in guiding research, and in this sense, research should be conducted within the rules founded by post-*positivism*, *constructivism*, or other robust paradigms. Research philosophy interested in the nature and development of knowledge (Saunders et al., 2009). Researcher philosophical point of view impacts the method of collecting and analysing the data regarding the particular phenomenon (Greenwood and Levin, 2006).

Choosing a general research paradigm is the selection between two essential research beliefs: *interpretive* and *positivist*. Both can be clarified based on epistemological, ontological, and methodological considerations in designing and carrying out the research. Research paradigm enables the study to recognise the required knowledge to address the research question(s), problem and strategies (i.e., methodologies) that can be utilised to gain, analyse and interpret the data (DePoy and Gitlin, 2015). The research philosophy encompasses key assumptions regarding how the researcher views the world (Saunders et al., 2009). These assumptions enable the researcher to choose an appropriate research strategy, methods, and techniques for the research. Choosing the most suitable research paradigm - in the technological innovation discipline - has been subjected to debate for a while. Orlikowski (2000) has recognised two perspectives of research paradigms are appropriate in research context of investigating the innovation adoption by organisations. These are *ontology* and *epistemology*.

4.3.1 Ontological Position

Ontology is the conception of the reality of the social world. The ontological assumptions attempt to investigate the nature of reality of the social world, whether it is inherent or marginal to the people concerned (Bryman, 2012). Two main ontological stances are recognised in the research paradigms: *objectivism* and *constructivism* (Matthews and Ross, 2010; Bryman, 2012). Objectivism is described by Bryman (2012, p.713) as "*an ontological position that asserts that social phenomena and their meanings have an existence that is independent of social actors*". This philosophical approach suggests that social phenomena facing us - as external realities – we cannot reach or influence them. The social world structures are objective bodies which are not subjected to human convictions, observations, culture and language that they explain. The objective world utilises scientific research, for instance, through the utilisation of experiments in data collection to test research hypotheses and theories (Fox et al., 2007). Objectivism permits the social phenomenon reality to be tested and verified utilising valid measures.

In contrast, Constructivism approach or subjectivism refers to "*an ontological position asserts that social phenomena and their meanings are continually being accomplished by social actors*" (Bryman, 2012, p.710). Constructivism stresses the dynamic position of social actors that is based on the perspective and subsequent actions of those actors in creating social reality and social phenomena. Social phenomena are continually changing as individuals and their society changes (Bryman and Bell, 2015). Mutual social reality is created through language as there is no one single reality (Fox et al., 2007). As a member of the social world, the researcher imputes their own implications, meanings and considerations to their study (Matthews and Ross, 2010).

The ontological position adopted in this study - as the most appropriate paradigm – is objectivism. This is manifested by the research's standpoint relying on the assumption that an objective reality (truth) about the studied phenomena (i.e., BIM adoption in

Architectural organisations) exists and it governs the mechanisms of BIM adoption in organisations. And, such an objective reality can be explained and achieved through an unbiased process of collecting and analysing data (i.e., obtained observations and reliable measurement).

4.3.2 Epistemological Position

Epistemology is defined as assumptions and beliefs of a paradigm that interested in constructing knowledge, and centres around how we recognise what we know or what are the most valid approaches to achieve truth (Neuman, 2013, p.95). Epistemology shows a philosophical stance for determining the types of knowledge that are feasible and confirming their adequacy and validity (Delanty and Strydom, 2003). Accordingly, three key epistemological positions can be recognised in the philosophy of knowledge construction (Saunders et al., 2009):

- **Positivism**: proposes that the truth (reality) is objectively delivered and can have measurable and quantifiable traits (Bryman, 2012). Positivists contend that discovering a single 'truth' can be achieved through an unbiased process and 'science' can be undertaken in a value-free and objective manner (Kothari, 2004). Hence, positivism in this way intends to introduce reliable forecasts and considerations of events or investigations. In the context of positivism research, the researcher seeks to decrease the field of investigation, concentrating on certain areas for collecting quantifiable data. This entails anticipating and clarifying causal relations among key factors. Usually, the positivist methodology plans to verify the suitability of an existing theory by building up a predefined hypothesis (i.e., empirical verification), and the social phenomena are clarified through viewing the causes and effects (Henn et al., 2005). The positivism stance comprises investigating the causal relationships using structured and systematic means involving formal recommendations, measurable variables, theories and hypotheses testing, and the drawing of results around the studied phenomenon from the sample to the targeted population (Orlikowski and Baroudi, 1991). Thus, the research design in positivist research paradigm must be highly organised with a large sample size, and requires a reliable statistical analysis (Henn et al., 2005).

- **Interpretivism**: contrary to positivism, interpretivism is defined as "*an epistemological position that requires the social scientist to grasp the subjective meaning of social action*" (Bryman, 2012, p.712). In this sense, the formation of social reality is contingent on the point of view of the researcher. Interpretivists argue that there is no single reality, rather a reality is associated with people's perceptions and circumstances. Subsequently, there is no global reality but many. Hence, interpretivism attempts to increase comprehension of the phenomenon in the setting in which it is created and through the diverse perceptions of the involved individuals or groups (Orlikowski and Baroudi, 1991). The interpretive process of the individuals' perceptions requires that the researcher recognises the 'socially constructed connotations' and reconstruct them in a 'social scientific language' (Blaikie, 2007). The interpretive research paradigm does not consider any predefined dependent and independent factors, rather reality is constructed from the obtained knowledge by social connotations (e.g., documents, language, shared behaviours, artefacts). Prejudice and subjectivity are common issues within the interpretive research paradigm. Henn et al. (2005) point out that interpretive research - to some extent - inclines to be unstructured and adaptable, however, it can be intended for a relatively small-scale data collection utilising a thorough yet descriptive position of the phenomena.

- **Realism**: Bryman (2012, p.715) defines realism as "*An epistemological position that acknowledges a reality independent of the senses that is accessible to the researcher's tools and theoretical speculations. It implies that the categories created by scientists refer to real objects in the natural or social worlds*". Realism is similar to positivism as both associates to scientific inquiry. Realism starts from positivism but is reinforced by the aid of the social reality of the fundamental structures or components (Matthews and Ross, 2010). As per such a view, there is no single study can be entirely value-free or objective (Henn et al., 2005). Realists or pragmatists believe that positivism and interpretivism are not really viewed as contrasting and irreconcilable perspectives. Instead, there is no one right strategy for science but numerous strategies (Hirschheim, 1985; Morgan, 2005). Kuhn (2012) contends that the research of natural sciences which adopts only a single perspective neglects the abnormal quality of human experience. Therefore, according to realism, social science research entails broadness of vision, tolerance, and an ability to acknowledge diverse methodologies and objectives rather than conformity (Orlikowski and Baroudi, 1991).

Aligned with the considered objectivist ontological position, this study adopts a positivist paradigm. Researchers' epistemological approach (i.e., beliefs about how knowledge is built) is strongly linked to ontological perception (i.e., the conception of reality). The positivist epistemology is closely tied with the objectivist ontology (i.e., single objective truth), whereas the interpretivist epistemology is connected to the constructivist ontology (i.e., multiple truths) (Bryman, 2012; Gray, 2017). As the purpose of this research is to determine the reality of events experienced by architectural organisations (i.e., provide an understanding of how intra-organisational BIM adoption and inter-organisational BIM diffusion occur), and given the quantitative nature underpinning most of the objectives (refer to Figure 4.2) addressed to fulfil this aim, a positivist stance is adopted in this research.

4.4 Research approach

Research approaches are generally categorised into three types including: deductive, inductive, and abductive research. These approaches determine how the relationship is perceived between the theory and research for each approach. Also, they can be distinguished according to the theory development and testing. For instance, research can start with a theory (i.e., existing theory testing), or research can result in theory (i.e., new theory building) (Bryman, 2012). **Deductive research** is the process that concerns the developing or affirming a theory that starts with general ideas and hypothetical connections and progresses toward further concrete empirical evidence (Neuman, 2013). In the deductive methodology, the researcher at first forms various speculations and hypotheses depending on theories and conceptual structures. Then, theory guides and impacts collecting and analysing the data, and the study addresses (tests) the hypotheses - presented by the theoretical assumption - by either confirming, refuting or modifying them (Bryman and Bell, 2015).

In contrast, **inductive research** is the process of formulating or affirming a theory that commences with concrete empirical evidence and progresses toward generalising the developed constructs (Neuman, 2013). In the inductive approach, the researcher assembles the ideas and theories depending on the collected empirical observations. This process comprises collecting and analysing the data that enables identifying various patterns that may propose the presence of specific connections among various ideas (Spens and Kovács, 2006).

While regarding the **abductive research**, it is an approach to theorising where some substitute frameworks are implemented to data and theory, that are re-explained in each and assessed. It implies creating iterative re-assessments of thoughts and data depending on applying alternative principles plans and learning from all (i.e., iterative discourse between conceptual inquiry and empirical observation) (Neuman, 2013). Abductive research addresses the frequently expected independence between technique and theory advancement or testing, and offers knowledge development through the repetitive discourse between data and a mixture of existing theories or suggestions (Dubois and Gibbert, 2010).

Given the study aims and objectives set out moving forward and backwards between theory and observations, the research combines cycles of deductive and inductive reasoning approaches, although the deductive approach remains the predominant one. The development of the taxonomy (Objective 1 and Part of objective 2) and the conceptual model to guide the empirical investigation of the BIM adoption process (part of Objective 2) adopted an inductive reasoning approach. The validation of the taxonomy (part of Objective 2) using Confirmatory Factor Analysis (inferential statistical test) to test the measurement models (i.e., Structural Equation Modelling) embraced a deductive reasoning approach. Then, the development of some of the conceptual constructs (i.e. two-dimensional characterisation model of BIM adoption in Objective 4, cause and effect diagraphs and causal loop diagrams in Objective 5, and the whole of Objective 6), assumed an inductive approach.

4.5 Research Strategy and methods

The employed inquiry approach is yet another perspective of research type that determines the method of collecting and analysing the data and can be classified to *quantitative* and *qualitative* research. **Quantitative** research typically focuses on quantifying measurement process of collecting and analysing data. Its research strategy usually incorporates positivist, objectivist, and deductive approach as the natural science research process. However, researchers who adopt this strategy do not always pledge to combine all the three stances (Bryman, 2012). Through the positivist principles, quantitative research utilises numeric forms to collect data and employs a deductive approach to initiate causal links between theory and research for analysing data (Bryman and Bell, 2015). For collecting data, surveys and experiments are the principal techniques of quantitative research. Quantitative research requires to obtain a larger sample size comparing to qualitative research (Fellows and Liu, 2015; Neuman, 2013).

Regarding the **qualitative** research, typically focuses on words (non-numeric form) instead of the quantification process of collecting and analysing data (Bryman, 2012). it depends on the textual technique for data collection and mainly utilises the inductive approach for data analysis with specific affirmation on the production of theories (Saunders et al., 2009; Bryman and Bell, 2015). Qualitative research predominantly embraces an interpretive paradigm and a subjectivist ontological position that considers many facts (multiple realities) and analyses data by examining entities within a given context and involves subjective connotations that social actors import to the situation (de Vaus, 2013). Qualitative research is frequently seen as less valid and reliable than quantitative research (Gray, 2017). Nevertheless, qualitative techniques have always been utilised in social science research (Neuman, 2013). Also, among several qualitative research methods, four main strategies can be identified including: ethnography, grounded theory, case study, and action research. Case studies are usually adopted as the primary form of qualitative research (Creswell and Creswell, 2017).

As stated by Creswell and Creswell (2017), the findings of quantitative research enable the researchers to generalise the effect among the study population. This study aims to attain results that are objective, valid and replicable for the BIM adoption process in architectural organisations. Thus, utilising of a quantitative approach combining survey research with inferential statistical methods and structural modelling approaches (i.e. F-DEMATEL) would address the study's aim and objectives.

4.6 Summary of the study methodological and philosophical choices

This section briefly summarises the adopted philosophical and methodological approaches mentioned in earlier sections. This study that predominantly falls into the class of explanatory research and secondarily within descriptive research. It combines cycles of **deductive** and **inductive** reasoning approaches. The **research philosophy** is **positivism** that presumes an **objective reality** exists. The research strategy is mainly **quantitative** (Monomethod), and it uses questionnaires surveys for empirical research. To visualise these choices, the 'Research Onion' model – developed by Saunders et al. (2009) – is employed. This model provides a systematic imaginary representation of how a given study shaping its structure (Figure 4.1).

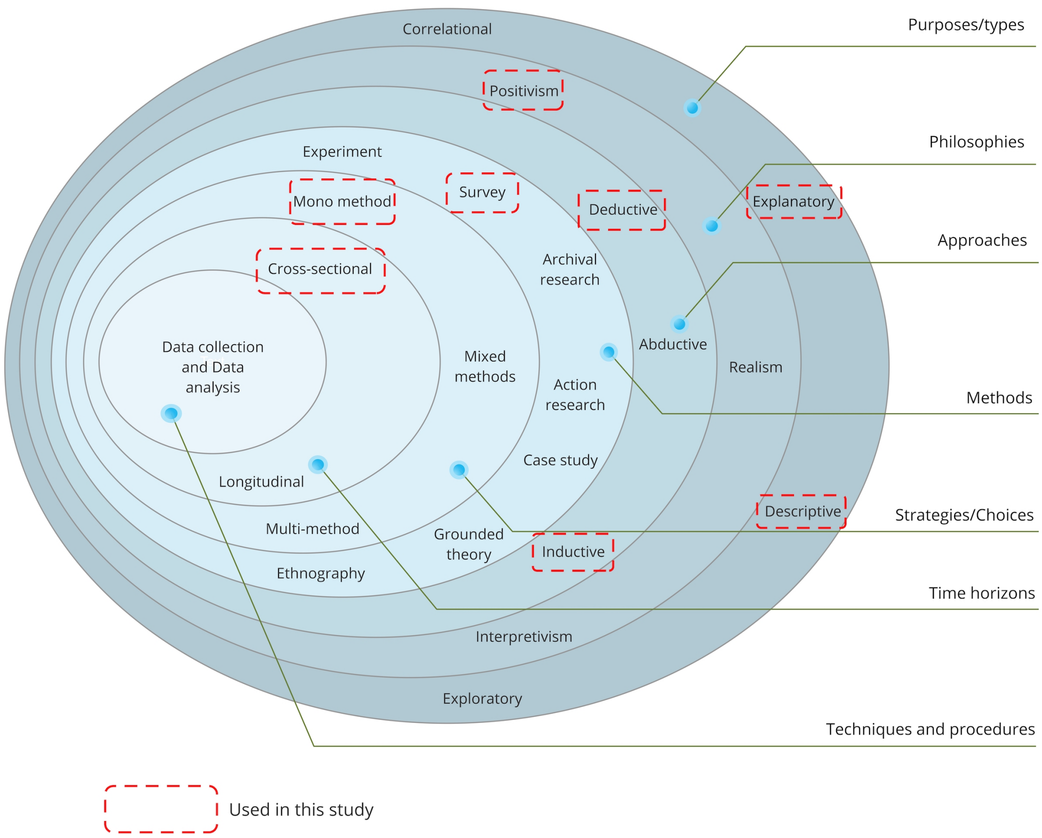


Figure 4.1 Research Onion adapted from Saunders et al. (2009)

4.7 Research design and applied methods

The aim of this retrospective (i.e., how intra-organisational BIM adoption and inter-organisational BIM diffusion has occurred) and cross-sectional study (i.e., the three-time horizons of the UK Government Construction/BIM Strategy of Pre-2011, 2011-2016, and Post-2016) is to "improve the understanding of the BIM adoption process within organisations and across markets by developing the necessary conceptual constructs and providing the supporting empirical evidence" (Ahmed and Kassem, 2018, p.104). To achieve this aim and its pertinent objectives, this study is designed to be carried out into a three-phase research approach (Figure 4.2). These phases are:

- **Phase 1**: This phase involves delivering background information about BIM and justifying the need for a new BIM innovation adoption research by providing evidence about the disruptive and multifaceted nature of BIM reported in the existing literature beyond the usual definitions. This step is a starting point to conduct a Systematic literature review (SLR) "to identify an extensive array of drivers and factors that influence the BIM adoption process in organisations, and the pertinent theoretical fundamentals and lenses (i.e., Innovation Diffusion Theory and Institutional Theory)" (Ahmed and Kassem, 2018, p.105). The SLR is performed using descriptive statistical analysis. Then, the SLR finding is used – in a knowledge synthesis – "to develop a Unified BIM Adoption Taxonomy (UBAT), and a conceptual model will guide the empirical investigation of the BIM adoption process" (Ahmed and Kassem, 2018, p.103) in the following phase.

- **Phase 2**: In this phase, a cross-sectional survey (i.e., a remote questionnaire survey) to collect primary data from a sample of 177 architectural organisations within the UK Architecture sector is developed and administrated. To validate the developed Unified BIM Adoption Taxonomy (UBAT), a Confirmatory Factor Analysis (CFA) – in the form of three Structural Equation Modelling (SEM) models - is used. The next step is understanding the effect of the taxonomy's drivers and factors on the BIM adoption by Architecture practices within the United Kingdom by identifying the most influencing drivers and factors on each of the three adoption stages (i.e., awareness, interest, and decision to adopt) and analysing their comparative influence. The next step comprises the formulation and testing a set of 51 hypotheses which are derived from the SLR findings and the taxonomy's constructs and their pertinent literature. "An Ordinal Logistic Regression analysis is employed (hypotheses testing) to understand the effect of the taxonomy's drivers and factors on the BIM adoption by Architecture practices within the United Kingdom by identifying the most influencing drivers and factors on each of the three adoption stages (i.e., awareness, interest, and decision to adopt) and analysing their comparative influence. Correlation Analysis is used to investigate the potential interplays among the 11 most influencing factors on the process of BIM adoption" (Ahmed and Kassem, 2018, p.111). The final step at this phase involves utilising a knowledge synthesis approach to develop Two-dimensional Characterisation Model of BIM adoption process including interplays between correlated pairs of adoption factors, organisation size (i.e., micro, small, medium, and large), and time (i.e., three time periods including pre-mandate period, implementation/trial period, and post-mandate period).

- **Phase 3**: This final phase is motivated by the need for a further understanding of the BIM adoption process that goes beyond the analysis of the correlation between pairs of factors and the ranking of factors. Therefore, this study develops another questionnaire survey (i.e., practitioner survey) with a sample of 12 responses (i.e., internal or external change agents), to inform the application of a structural modelling (i.e., Fuzzy Decision-making trial and evaluation laboratory – FDEMATEL) to cluster adoption factors into cause and effect groups (i.e., digraphs and impact relation maps), and Systems Thinking Models' techniques to map causal relationships and develop causal loop diagrams (CLDs). Finally, linking the industry player group(s) to the corresponding adoption factor(s) upon which they exert a certain degree of influence to demonstrate how the results from the developed causal loop diagrams can inform the development and implementation of BIM adoption strategies.

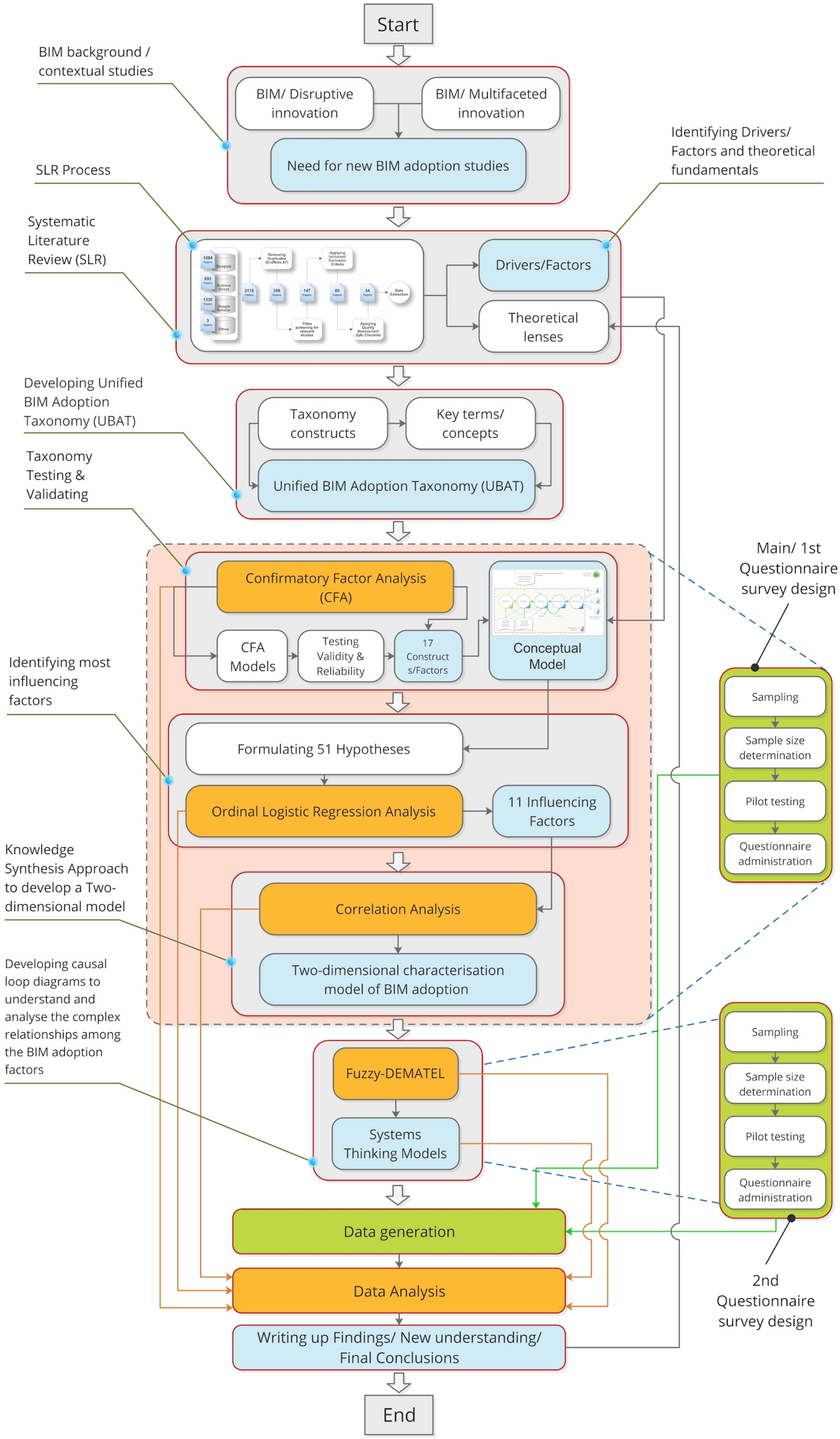


Figure 4.2 Research Design and applied methods and techniques to this study

4.8 Questionnaire and data organisation

This section comprises all preparation processes attributed to the quantitative survey: Sampling and data collection; questionnaire development and pilot testing; determination of sample size; reliability of the sample size; and the normality of the Data.

4.8.1 Sampling and data collection

Architectural organisations operating in the United Kingdom Architecture, Engineering and Construction (AEC) are targeted in this survey. These architectural firms (i.e., 509 Chartered Practices) are listed as BIM service providers by the "Royal Institute of British Architects (RIBA). A criterion is set that the respondents should be knowledgeable about the process that led their organisation to adopt BIM. In these practices, the key individuals who are directly involved in the decision to adopt BIM (e.g., directors, partners, BIM managers, etc.) are identified and approached" (Ahmed and Kassem, 2018, p.108). A database of the contact details (i.e., publicly listed information on the practices websites and the RIBA) of the potential targeted respondents are prepared and matched with a professional internet platform (i.e., LinkedIn) to facilitate contacting the respondents. An online tool (i.e., Google Forms) is used to publish the questionnaire online. The questionnaire is emailed to qualified potential respondents. An invitation letter is enclosed into the email with a website hyperlink that direct participants to the online questionnaire. A follow-up procedure (i.e., phone calls and reminder emails) is carried out to encourage the non-respondents after two weeks to improve the response rate. The data were collected from mid-January 2017 to early August 2017 using the same monitored and administered online tool (Google Forms). Out of a total of 509 questionnaires, "177 valid responses were returned, and 6 incomplete responses were discarded, with an approximate response rate of 36%" (Ahmed and Kassem, 2018, p.108).

4.8.2 The questionnaire development and pilot testing

This study has employed a questionnaire survey to collect the data required for testing the hypotheses and validating the developed BIM adoption-decision process conceptual model and other developed conceptual constructs in this study. A structured questionnaire that includes two sections was devised and used to collect the empirical data (See the whole questionnaire in Appendix B). This questionnaire is the primary data collection technique and the main questionnaire survey (i.e., apart from the second questionnaire that will be devised for conducting the F-DEMATEL in Chapter 8).

The first section was intended to capture demographic information, for example, "organisation size, number of BIM projects, and dates of formulating BIM adoption decision" (Ahmed and Kassem, 2018, p.108) (i.e., the time horizon of the UK Government Construction/BIM Strategy 2011-2015). The second section of the questionnaire was aimed at obtaining the respondent agreement with 77 various statements (i.e., measurement items of the BIM adoption taxonomy's constructs) using a five-point Likert scale. These statements were grouped under three categories: External Environment Characteristics, BIM Perceived Attributes, and Internal Environment Characteristics. The scale was ranging from 'strongly disagree' to 'strongly agree'. From prior studies (i.e., the 37 selected studies listed in Table 3.5 of the SLR outcome), measurement items were derived and reworded to fit in with their relevant constructs (i.e., factors) of BIM adoption (Table 4.1).

For the pilot testing of the questionnaire, Francis et al. (2004) suggest that a minimum of five responses is required for a questionnaire validity. Hence, eight responses were recruited for clarity and understanding of the questionnaire. In addition, three senior academics were asked who revised the questionnaire statements and questions. Participants' feedback suggested a few expressions required rewording. Revising process to improving the design of the questionnaire is crucial prior to embarking the actual fieldwork (Rattray and Jones, 2007; Sexton et al., 2006).

Table 4.1 The 77 measurement items of the main questionnaire survey of this study

Drivers	Factors	Questionnaire statements	Reference	Code
External environment characteristics	Coercive pressures	1- Our main clients believe that we should use BIM	(Liu et al., 2010), (Cao et al., 2014), (Sherer et al., 2016)	XA_Q1
		2- Our trading partners put pressure upon us to use BIM	(Liu et al., 2010), (Cao et al., 2014), (Sherer et al., 2016)	XA_Q2
		3- We may not retain our important clients without BIM	(Liu et al., 2010), (Tsai et al., 2013)	XA_Q3
		4- We have adopted BIM to respond to the BIM level 2 mandate by the UK government	(Liu et al., 2010), (Cao et al., 2014), (Sherer et al., 2016)	XA_Q4
		5- Non-adoption of BIM, may lead to contractual sanction	(Liu et al., 2010), (Tsai et al., 2013)	XA_Q5
	Mimetic pressures	6- Our main competitors have adopted BIM and benefited from it	(Liu et al., 2010), (Cao et al., 2014), (Sherer et al., 2016)	XB_Q6
		7- Our main competitors who have adopted BIM are perceived favourably by clients	(Liu et al., 2010), (Cao et al., 2014), (Tsai et al., 2013), (Sherer et al., 2016)	XB_Q7
		8- Our main competitors who have adopted BIM are more competitive	(Liu et al., 2010), (Cao et al., 2014), (Sherer et al., 2016)	XB_Q8
		9- It is important to benchmark our BIM adoption against our main competitors	(Liu et al., 2010), (Cao et al., 2014)	XB_Q9
		10- Potential BIM adopters may imitate their main competitors' implementations	(Sherer et al., 2016), (Tsai et al., 2013)	XB_Q10
		11- Potential BIM adopters imitate the behaviour of other firms within their network	(Sherer et al., 2016), (Cao et al., 2014), (Yitmen, 2007)	XB_Q11
	Normative pressures	12- BIM has already been widely adopted by our clients	(Liu et al., 2010), (Tsai et al., 2013)	XC_Q12
		13- BIM has been widely adopted by the architectural, engineering, and construction industry (AEC)	(Liu et al., 2010), (Tsai et al., 2013)	XC_Q13
		14- The BIM norms, standards, and policies motivated and helped our organisation to adopt BIM	(Cao et al., 2014), (Hameed et al., 2012),	XC_Q14
		15- BIM champions played a significant role in BIM diffusion	(Cao et al., 2014), (Sherer et al., 2016), (Takim et al., 2013)	XC_Q15
		16- The BIM external consultants influenced and facilitated our decision to adopt BIM	(Cao et al., 2014), (Sherer et al., 2016), (Hameed et al., 2012)	XC_Q16
Innovation characteristics	Relative advantage	17- Adopting BIM is perceived to improve the productivity of our organisation	(Oliveira et al., 2014), (Tsai et al., 2010), (Henderson et al., 2012), (Kim et al., 2015), (Seed, 2015)	YA_Q17
		18- Adopting BIM is perceived to reduce overall cost	(Tsai et al., 2010), (Kim et al., 2015), (Seed, 2015)	YA_Q18
		19-Adopting BIM is perceived to shorten duration of a construction project	(Oliveira et al., 2014), (Kim et al., 2015), (Seed, 2015)	YA_Q19
		20- Adopting BIM can mitigate risk	(Oliveira et al., 2014), (Tsai et al., 2010), (Kim et al., 2015), (Seed, 2015)	YA_Q20
		21- Adopting BIM is perceived to improve task performance	(Oliveira et al., 2014), (Tsai et al., 2010), (Kim et al., 2015), (Seed, 2015)	YA_Q21
		22- Adopting BIM is perceived to be advantageous in our organisation	(Oliveira et al., 2014), (Seed, 2015)	YA_Q22
	Compatibility	23- Adopting BIM is perceived to be compatible with existing processes in our organisation	(Son et al., 2015), (Davies and Harty, 2013), (Gledson and Greenwood, 2017), (Henderson et al., 2012)	YB_Q23
		24- Adopting BIM is perceived to be compatible with our organisation culture and values	(Son et al., 2015), (Davies and Harty, 2013), (Henderson et al., 2012)	YB_Q24
	Complexity	25- Adopting BIM makes our work easier	(Kim et al., 2015)	YC_Q25

		26- We adopted BIM because it is easy to learn	(Kim et al., 2015)	YC_Q26
		27- Adopting BIM is perceived to improve collaboration in our organisation	(Tsai et al., 2010)	YC_Q27
		28- Adopting BIM is perceived to be too complex for business operations	(Oliveira et al., 2014), (Ahuja et al., 2016)	YC_Q28
	Trialability	29- Trying out BIM features before adoption in practice provides the possibility of risk reduction	(Ahuja et al., 2016), (Kim et al., 2015)	YD_Q29
		30- We adopted BIM after a trial period	(Ahuja et al., 2016), (Kim et al., 2015)	YD_Q30
	Observability	31- The positive results of adopting and implementing BIM support its diffusion	(Kim et al., 2015), (Waarts et al., 2002)	YE_Q31
		32- We adopted BIM as its positive effects were evident	(Kim et al., 2015), (Damanpour and Gopalakrishnan, 2001)	YE_Q32
		33- Our organisation has the intention to recommend BIM to others	(Kim et al., 2015)	YE_Q33
	Technological factors	34- BIM interoperability across different platforms was key in the decision to adopt	(Xu et al., 2014), (Waarts et al., 2002)	YF_Q34
		35- Adopting BIM is perceived to improve the visualisation of design effects	(Xu et al., 2014)	YF_Q35
		36- The availability and affordability of BIM technology were key in the decision to adopt BIM	(Waarts et al., 2002)	YF_Q36
		37- The investment cost of BIM technology (software, hardware, training) did not affect our decision to adopt BIM	(Xu et al., 2014)	YF_Q37
Internal environment characteristics	Top management support	38- Our top management has the willingness to support change	(Xu et al., 2014), (Mom et al., 2014),	ZA_Q38
		39- The general attitude of our organisation towards innovation facilitates the decision to adopt BIM	(Mom et al., 2014), (Arayici et al., 2011)	ZA_Q39
		40- The senior management of our organisation encouraged the decision to adopt BIM	(Mom et al., 2014), (Hameed et al., 2012)	ZA_Q40
	Communication behaviour	41- Our organisation has effective communication channels and networking within the architectural, engineering, and construction industry (AEC)	(Mom et al., 2014), (Henderson et al., 2012)	ZB_Q41
		42- Our organisation initiated a network of connections to know more about BIM when we first time had heard about it	(Murray et al., 2007), (Hameed et al., 2012)	ZB_Q42
		43- Our organisation has direct communication with the early adopters of BIM	(Mom et al., 2014), (Gorse and Emmitt, 2007)	ZB_Q43
		44- The internet/social media helped our organisation to understand more about BIM	(Mom et al., 2014), (Murray et al., 2007)	ZB_Q44
		45- Interpersonal channels helped our organisation to understand more about BIM	(Murray et al., 2007), (Henderson et al., 2012)	ZB_Q45
	Financial resources	46- Our organisation has allocated a yearly budget for IT technologies that facilitated the decision to adopt BIM	(Mom et al., 2014), (Waarts et al., 2002)	ZC_Q46
		47- The required cost to secure BIM was a key element in the decision to adopt	(Mom et al., 2014)	ZC_Q47
		48- Our organisation perceived BIM as an affordable innovation	(Mom et al., 2014)	ZC_Q48
		49- Our organisation has adopted BIM as its implementation cost was affordable	(Mom et al., 2014), (Ahuja et al., 2016)	ZC_Q49

	Organisational readiness	50- Our organisation has provided sufficient training to our staff as a preparation for BIM adoption	(Mom et al., 2014)	ZD_Q50
		51- Our ability to adapt the technologies enabled us to adopt BIM	(Tsai et al., 2010), (Mom et al., 2014)	ZD_Q51
		52- Our organisation has provided a professional BIM technology training	(Mom et al., 2014)	ZD_Q52
		53- Technological capability of organisation is key to the decision to adopt BIM	(Tsai et al., 2013)	ZD_Q53
		54- Our organisation has employed experienced staff to adopt BIM	(Ramanayaka and Venkatachalam, 2015)	ZD_Q54
		55- Our organisation has the capability of training and support when it comes to obtaining new innovative technology	(Mom et al., 2014)	ZD_Q55
		56- The technical competence of staff should be considered before taking the decision to adopt BIM	(Shim et al., 2009), (Henderson et al., 2012)	ZD_Q56
		57- Research and development capability of an organisation is required to adopt BIM	(Mom et al., 2014)	ZD_Q57
		58- BIM adoption requires the availability and effectiveness of human capability/resource for keeping the best people	(Shim et al., 2009), (Henderson et al., 2012)	ZD_Q58
		59- BIM adoption requires intra-organisational management support	(Tsai et al., 2010), (Tsai et al., 2013)	ZD_Q59
		60- BIM adoption requires prior experience and IT expertise	(Tsai et al., 2010), (Tsai et al., 2013), (Shim et al., 2009)	ZD_Q60
	Social motivations	61- It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption	(Mom et al., 2014), (London and Singh, 2013)	ZE_Q61
		62- It was necessary to manage people who were resistant to change towards BIM	(Mom et al., 2014), (London and Singh, 2013)	ZE_Q62
		63- The decision to adopt BIM is affected by the attitudes and perceptions (positive/negative) towards the type of innovation (BIM)	(London and Singh, 2013), (Waarts et al., 2002), (Peansupap and Walker, 2005a)	ZE_Q63
		64- Social pressures are captured based on managers' perceptions rather than an actual understanding of the real world	(Shim et al., 2009)	ZE_Q64
		65- It is necessary to maintain the championing image motives of a good using of advance technologies to facilitate the BIM adoption	(Hameed et al., 2012), (Cao et al., 2016)	ZE_Q65
	Organisational culture	66- Enabling environment of an organisation is required to adopt BIM	(Abubakar et al., 2014), (Mom et al., 2014)	ZF_Q66
		67- BIM adoption requires organisational flexibility/adaptability to market	(Mom et al., 2014)	ZF_Q67
		68- Corporate management style (e.g. family owned or public owned) affects the decision to adopt BIM	(Mom et al., 2014)	ZF_Q68
		69- BIM adoption requires open discussion within an organisation	(Mom et al., 2014), (Hameed et al., 2012)	ZF_Q69
		70- BIM adoption requires organisational restructuring	(Mom et al., 2014)	ZF_Q70
	Willingness/ intention	71- BIM adoption helps to achieve competitive advantages in the market	(Gu and London, 2010), (Mom et al., 2014), (Peansupap and Walker, 2005b), (Takim et al., 2013), (Rogers et al., 2015)	ZG_Q71
		72- Our organisation has adopted BIM to acquire interest in our business	(Gu and London, 2010), (Tsai et al., 2013)	ZG_Q72

		73- Our organisation has the need to innovate	(Singh and Holmstrom, 2015)	ZG_Q73
		74- The need for innovativeness is necessary to adopt BIM	(Singh and Holmstrom, 2015), (Talukder, 2012)	ZG_Q74
		75- Before adopting BIM, our organisation had the interest to learn BIM	(Xu et al., 2014), (Tsai et al., 2013)	ZG_Q75
	Organisation size	76- The size of an organisation is positively related to its readiness to adopt BIM	(Hameed et al., 2012), (Tsai et al., 2013)	ZH_Q76
		77- The number of company employees is positively related to its readiness to adopt BIM.	(Hameed et al., 2012), (Tsai et al., 2013)	ZH_Q77

4.8.3 The determination of sample size

The survey was aimed at soliciting information from a more extensive sample by ascertaining the respondents' opinions based on knowledge of how their architectural organisations made the decision to adopt BIM. Due to time limitations, it is unmanageable to sample the entire population of the architectural firms operating in the UK AEC. Hence, certain techniques were adopted to select a sizeable but illustrative sample size for the survey. Sampling techniques must be adapted to suit the situation of the data being collected (Oppenheim, 2000). Random sampling is the most recommended method for surveys of this nature (Creswell et al., 2003). It is an approach that usually includes the 'systematic collection' of respondents, of which each part within the population has an equivalent possibility of being chosen (Oppenheim, 2000). Random sampling entails the correspondence of the 'sample frame' of a population and includes the utilisation of a statistical technique to identify an illustrative minimum sample size (Creswell et al., 2003). This study adopted the listed number (509 practices) of the registered firms, that recognised as BIM service providers (RIBA, 2017) by the Royal Institute of British Architects, as the population size in this survey.

To determine the appropriate sample size for the survey, formula Equation 4.1 from Select Statistical Services (Select Statistical Services, 2017) was used in this study. This technique has been widely adopted in determining the minimum sample size, for example; (Ahadzie, 2007; Ankrah, 2007; Baba, 2013; Mahamadu, 2017; Manu, 2014).

Equation 4.1 Minimum Sample Size Determination Formula

$$Ss = \frac{Z^2 \times P(1-P)}{C^2} \quad (1)$$

Where:

Ss= Sample size;

Z= standardised variable (i.e., critical value of the Normal distribution)
P= sample proportion (i.e., 50%)
C= confidence interval (i.e., ±10%)

Likewise with most other research, 95% as a confidence level was assumed which resulted in a Z of 1.96 (i.e., based on a significant level of *P*= 0.05). In order to achieve accuracy, Blair et al. (2013) recommended assuming the proportion sample as p=50%, with a confidence interval (C) of ±10% as a 'Margin of error' (Maisel and Persell, 1996). Therefore, the minimum sample size for the survey in this study was calculated as follows (Equation 4.2):

Equation 4.2 Calculation of the sample size generally

$$Ss = \frac{1.96^2 \times 0.5(1-0.5)}{0.1^2}$$

$$Ss = 96.04 \quad (2)$$

Based on the calculation, the approximate sample size of the required number of architectural firms for the questionnaire is 96. However, it is required to adjust this figure relative to the estimated population size using the formula in Equation 4.3 (Blair et al., 2013).

Equation 4.3 Adapted Sample Size Formula

$$Adapted\ Ss = \frac{Ss}{1 + \frac{Ss - 1}{Ps}} \tag{3}$$

Where: Ps = Population size

The total estimated population size of the architectural firms listed by the RIBA (2017) as BIM service providers is 509 firms. The adapted sample size is calculated as shown in Equation 4.4.

Equation 4.4 Adapted Sample Size Calculation

$$Adapted\ Ss = \frac{96.04}{1 + \frac{96.04 - 1}{509}} \tag{4}$$

$$Adapted\ Ss = 80.92$$

The adapted sample size regarding the total estimated population of the architectural firms that provide BIM services is approximately equal to 81, which is relatively considered adequate to achieve a normal sampling distribution. However, due to the poor responses to questionnaire surveys notorious of the UK AEC (Ankrah, 2007; Baba, 2013), it is recommended to readjust the sample considering 20%-30% of non-response rate (Ankrah, 2007; Baba, 2013; Mahamadu, 2017). Therefore, a rate of 20% is assumed as a conservative response rate, as shown in Equation 4.5.

Equation 4.5 Survey Sample Size Calculation

$$Survey\ Sample\ size = \frac{Adapted\ Ss}{0.2} = \frac{81}{0.2} \tag{5}$$

$$Survey\ Sample\ size = 405$$

4.8.4 The Reliability of the sample size

To assess the reliability of the sample size based on the confidence of the collected data, 17 constructs (i.e. factors) and 77 variables (i.e., questionnaire's statements) were tested using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy statistical test. The results showed that all the 77 variables exceeded the minimum criterion of 0.5 (Kaiser and Rice, 1974), ranging from 0.558 to 0.892. These results achieved the confidence of the sample size as shown in Table 4.2 (below), and Table C.1 (in Appendix C).

Table 4.2 (KMO) Measure of Sampling Adequacy

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.732
Bartlett's Test of Sphericity	Approx. Chi-Square	9359.069
	df	2926
	Sig.	.000

4.8.5 The Normality of the Data

To assess the normality of data distribution, two statistical indicators were used: Skewness and Kurtosis. According to Peat and Barton (2008), "*Values that are between +3 and -3 represent a good indicator that the variables are normally distributed*". In addition, it is recommended that the values of skewness <2 and Kurtosis <7 to achieve a normal distribution of data (Kim et al., 2014; West et al., 1995). Having applied these criteria, the results showed that all the 77 items of the questionnaire used in this study were normally distributed. In this manner, there are no activities required to treat the data, and will be used as input for the upcoming stages of analysis and testing the study model. Table C.2 (in Appendix C) shows the result of the Normality of Data Distribution.

4.9 General survey results

This section comprises the general survey results (i.e., demographic information): organisation size, number of BIM projects, and dates/time horizons regarding BIM adoption decision. The demographic results are presented in the following sections using frequency measures (frequency, percentage, and count) and central tendency measures (mean and median).

4.9.1 Organisation Size

In this study, four categories of architectural organisation sizes were predefined based on the number of employees: ‘Micro’ (less than 10 employees); ‘Small business’ (10 - 49 employees); ‘Medium-sized business’ (50 - 249 employees); and ‘Large business’: (250 employees or more). Large firms represent 28.25% of the total responses of the sample. Micro firms come second with 24.86% followed closely by small firms (24.29%) with the least for medium-sized organisations (22.6%) (Figure 4.3).

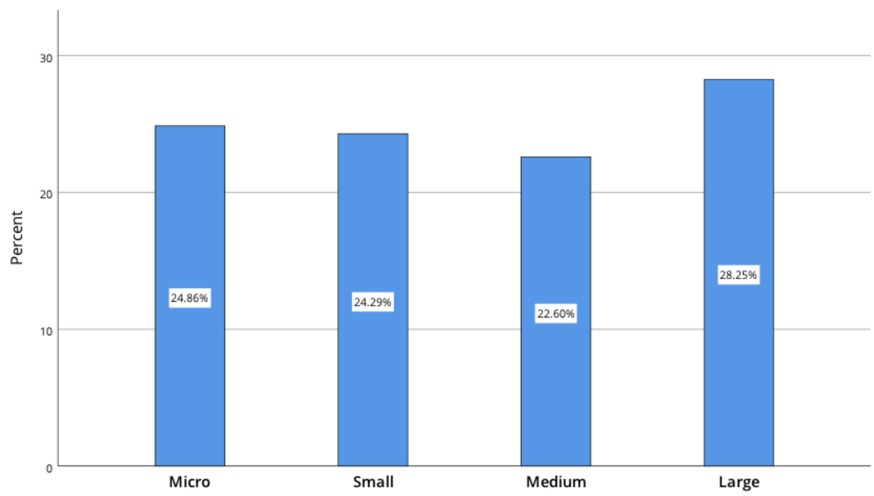


Figure 4.3 Types of organisation sizes

4.9.2 BIM projects

The responses showed that the number of BIM projects ranged between 1-100. Large architectural organisations had the highest percentage among all other organisation sizes at 56.22% (mean=97). The second highest was recorded by medium-sized organisations with 29.04% (mean=50). Micro organisations had 8.81% (mean=15) followed by 5.93% (mean=10) for small organisations. Figure 4.4 shows the percentages of BIM-based projects by the four organisations sizes.

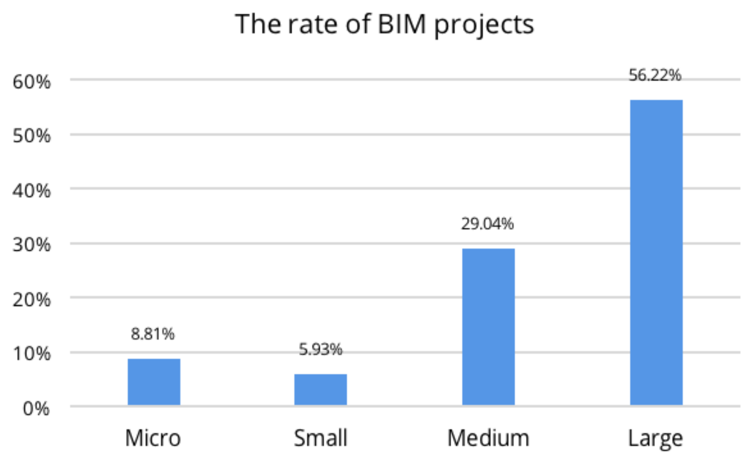


Figure 4.4 The rates of BIM projects

4.9.3 Time horizons of BIM adoption process in the UK

In this study, "three ordinal interval stages – of the proposed BIM adoption-decision process conceptual model – were identified, namely: *awareness*, *intention*, and *decision*. These stages have considered the time horizon of the UK Government BIM Mandate (i.e., pre-announcement of BIM mandate/pre-2011; trial implementation period of BIM mandate/2011-2016; and post-mandate/post-2016). In the questionnaire, the participants were asked to indicate indicative dates such the year when they first heard about BIM (i.e., Awareness); formulated a favourable attitude towards BIM (i.e., Intention), and made the decision to adopt BIM (i.e., Decision). This section demonstrates (1) the overall trend of the rates of BIM adoption process by architectural organisations based on the three stages (i.e., awareness, intention, and decision to adopt), then (2) the distribution of organisations sizes across three stages of BIM adoption (i.e., micro, small, medium, and large), and finally (3) the percentages of architectural organisations at each stage of the adoption process while considering the time horizon of the UK Government Construction/BIM Strategy and organisation sizes" (Ahmed and Kassem, 2018, p.113).

4.9.3.1 The overall trend of the BIM adoption process percentage

Regarding the '**Awareness**' stage, Figure 4.5 depicts when first BIM adopters became aware of BIM (1.13% in 1997 and 2.26% in 2000) respectively. Between 2005 and 2010 the percentage of BIM awareness dramatically increased from 3.39% to the highest score of 19.77% in 2010 with an overall cumulative percentage (59.87%) among the selected sample of adopters. Then, for the period 2011-2016, the cumulative percentage was (40.13%).

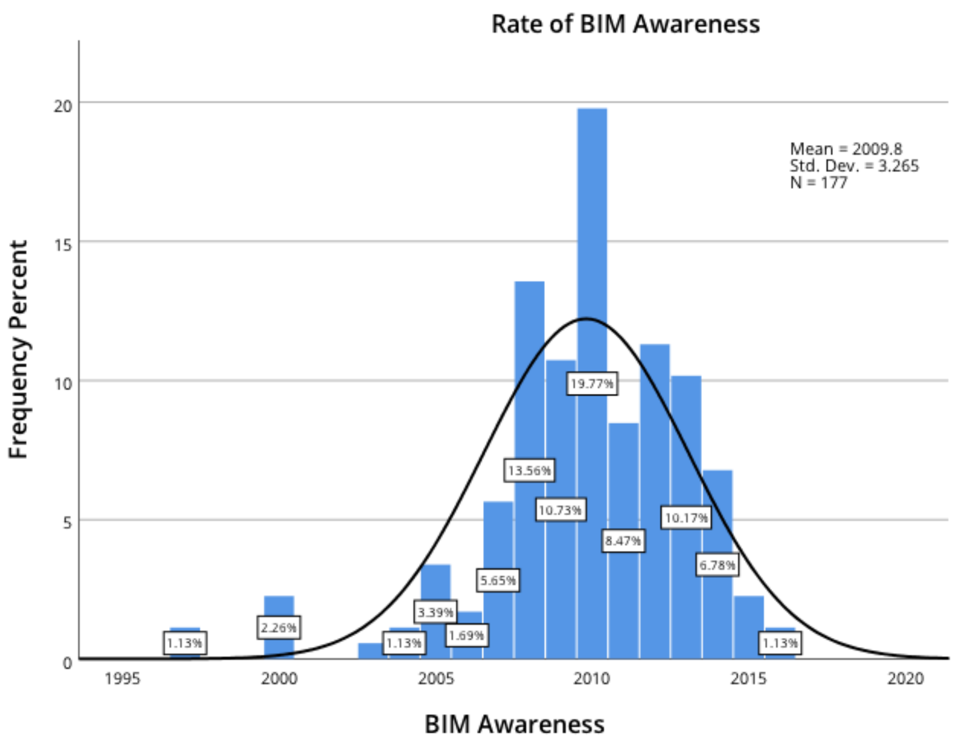


Figure 4.5 A Histogram chart of the normal distribution curve (Bell curve) of BIM Awareness

At the '**Intention**' stage, the earliest BIM adopters (0.56%) first started to formulate a favourable attitude towards BIM adoption in 2000. In late 2006, the percentage of BIM intention (3.95%) dramatically increased reaching to the highest level (16.38%) in 2013. Cumulatively, the percentages for the periods pre-2011 and 2011-2016 were (24.81%) and (74.06%), respectively. Figure 4.6 illustrates the histogram chart of the normal distribution curve (Bell curve) of the Intention in BIM rates.

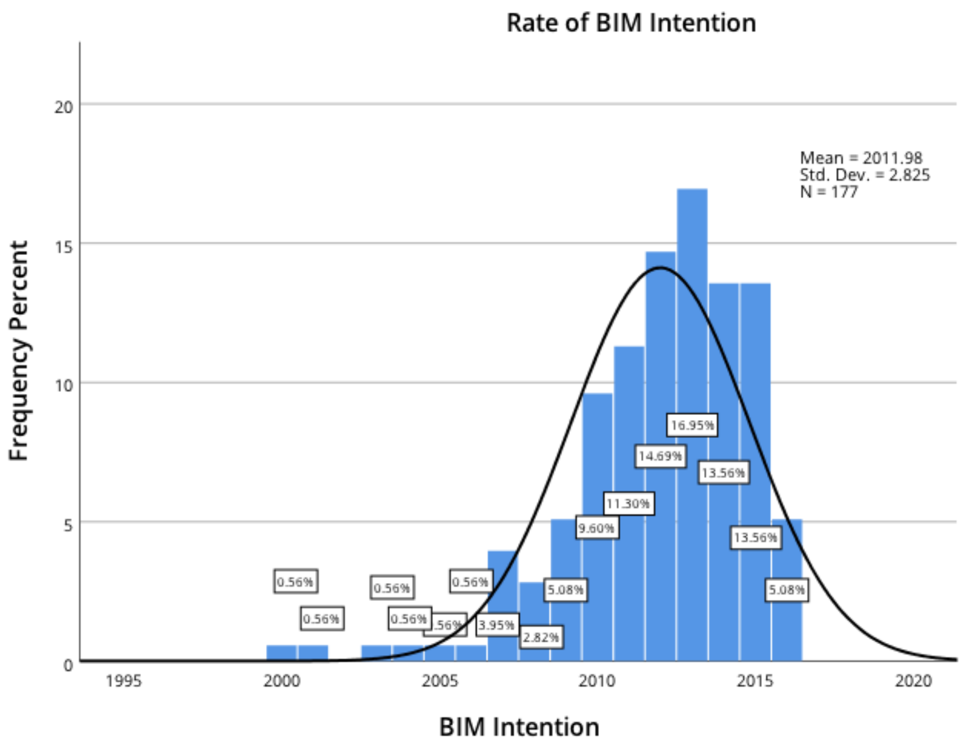


Figure 4.6 A Histogram chart of the normal distribution curve (Bell curve) of the Intention in BIM

Lastly, at the '**Decision**' stage, the earliest BIM adopters (0.56%) first made the decision to adopt BIM in 2000. Between 2007 and 2013, the percentage of BIM adopters dramatically grew from 3.95% reaching to the highest level of 15.82% in 2013. Cumulatively, the percentages for the periods pre-2011 and 2011-2016 were (17.5%) and (79%) respectively. Figure 4.7 illustrates the histogram chart of the normal distribution curve (Bell curve) of the Decision stage.

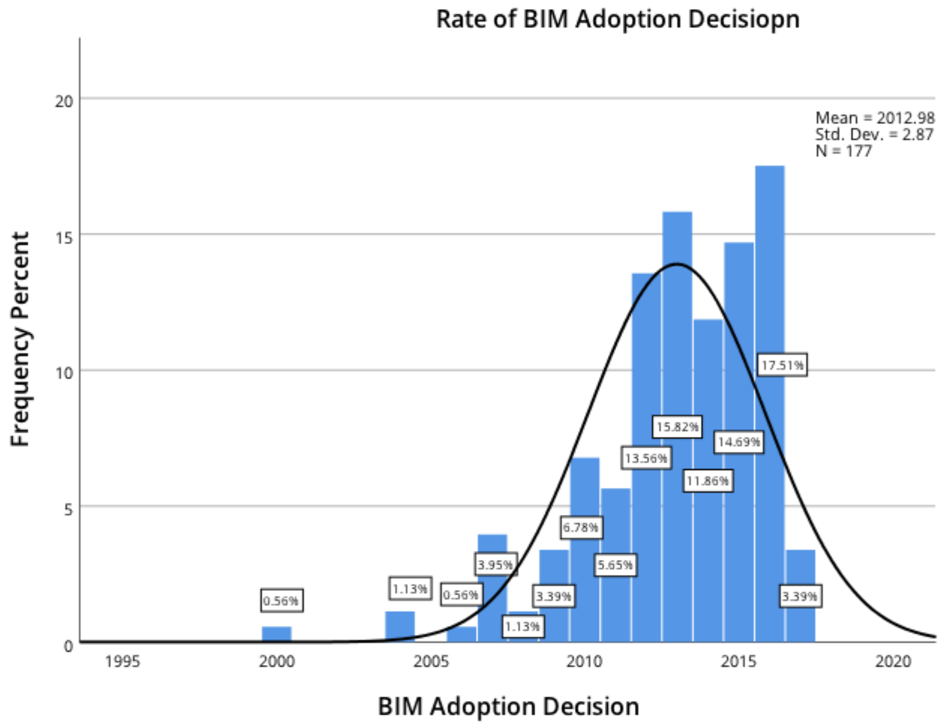


Figure 4.7 A Histogram chart of the normal distribution curve (Bell curve) of the BIM Adoption Rate

Finally, Figure 4.8 summarises the "three stages of BIM adoption process considering the three-time horizons" (Ahmed and Kassem, 2018, p.113). It shows the transitional periods between two consecutive stages, and the intertwined period when all activities of the three stages occurred.

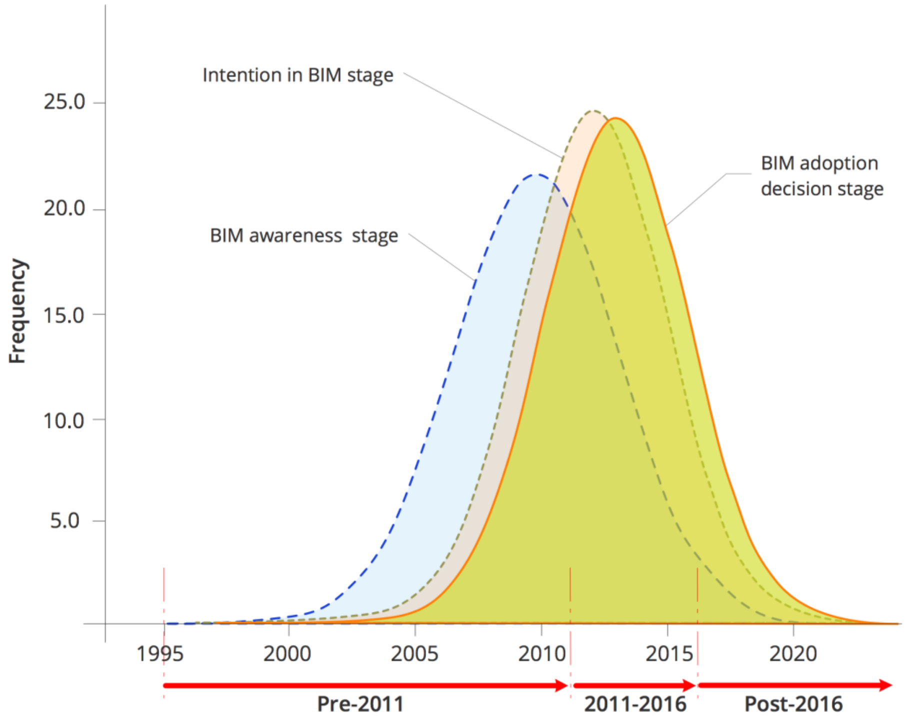


Figure 4.8 The rates of BIM adoption process stages

4.9.3.2 The distribution of organisations sizes across three stages of BIM adoption

As shown in the bar chart (Figure 4.9), the medium-sized organisations had the earliest mean for their BIM awareness, intention to adopt BIM, and the decision to adopt BIM. The averages were in 2009.2, 2011, and 2012.1 respectively, followed closely by the large organisations at averages of 2009.4, 2011.7, and 2012.8 respectively. Then, Micro organisations with averages of 2010.1, 2012.34, and 2013.4, followed by the Small organisations with averages of 2010.5, 2012.7, and 2013.6 for the dates of BIM awareness, intention to adopt BIM, and the decision to adopt BIM, respectively.

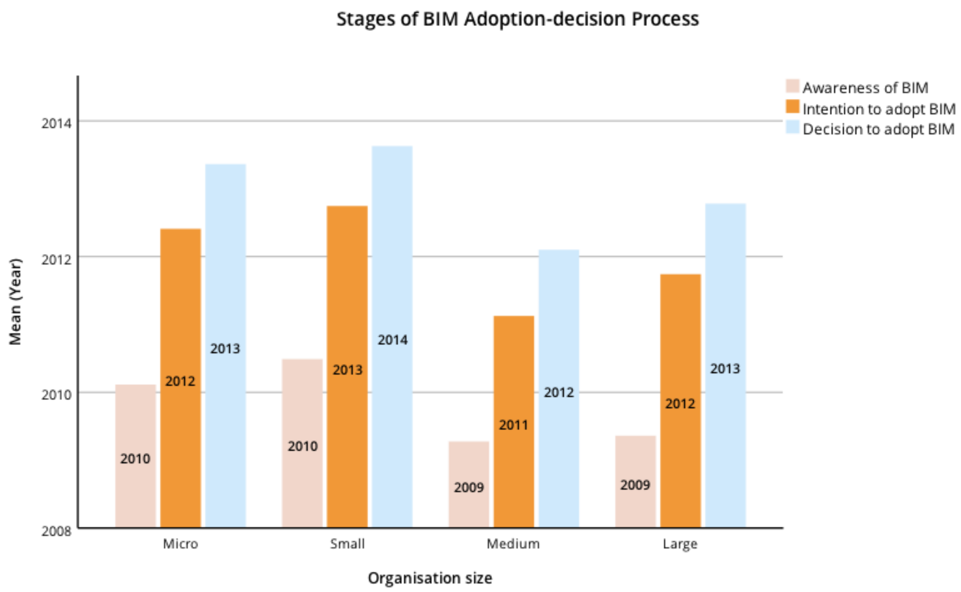


Figure 4.9 Stages of BIM adoption-decision process against organisation sizes

4.9.3.3 Comparing the distribution of organisations sizes across three stages of BIM adoption and time horizon

The following bar charts Figure 4.10, Figure 4.11, and Figure 4.12 show the comparison rates of BIM awareness, BIM intention, and BIM adoption decision, among the four categories of organisation sizes (i.e., micro, small, medium, and large) while considering the three-time horizon (i.e., the time horizon of the UK Government Construction/BIM Strategy).

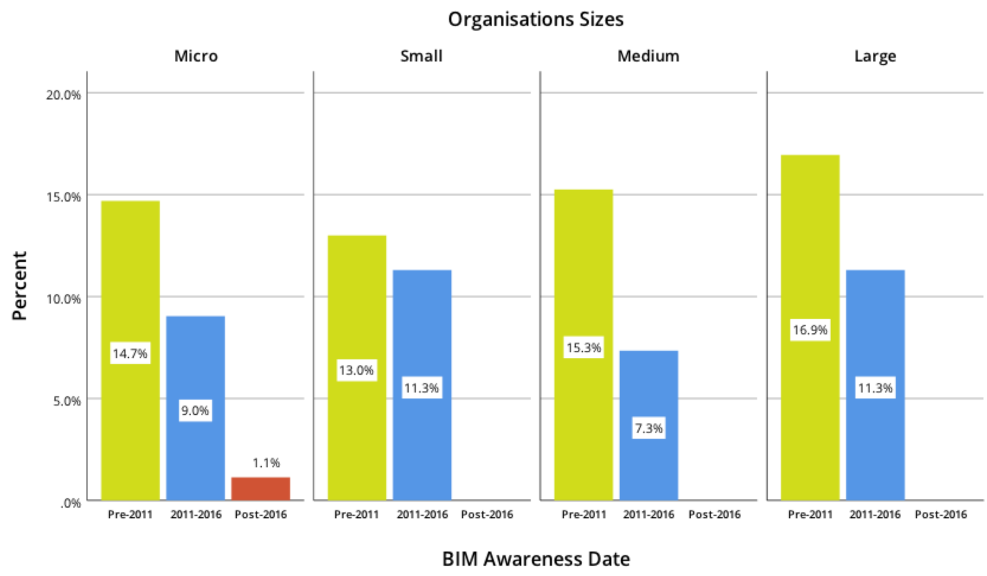


Figure 4.10 The participatory percentages of BIM awareness against organisation sizes and time horizon

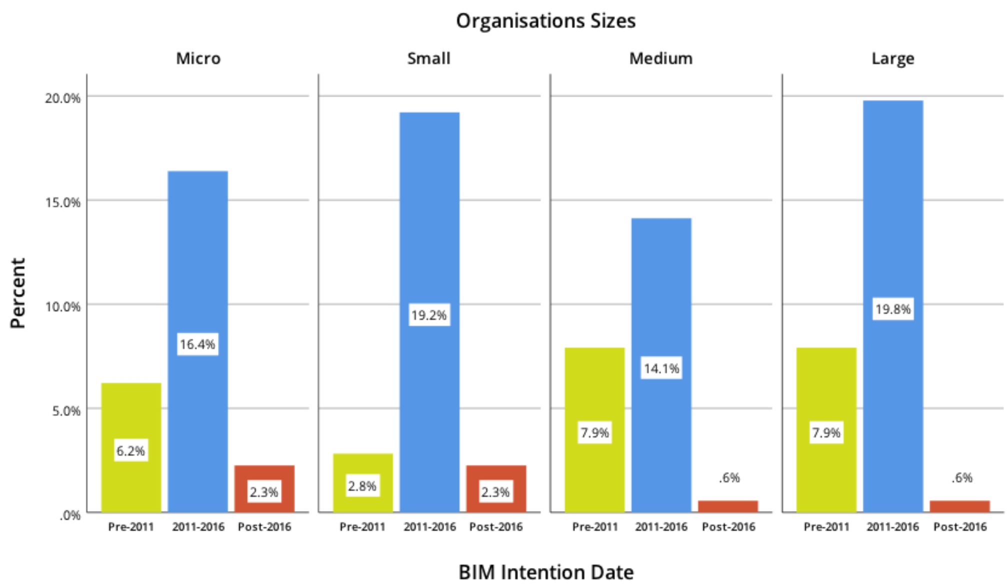


Figure 4.11 The participatory percentages of the Intention in BIM against organisation sizes and time horizon

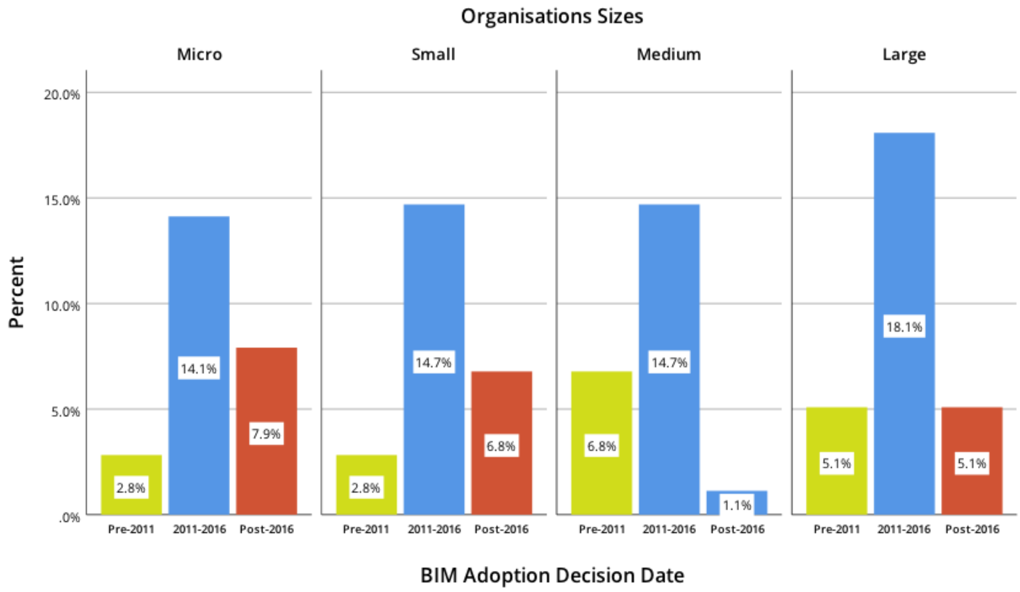


Figure 4.12 The participatory percentages of Decision to adopt BIM against organisation sizes and time horizon

4.10 Ethical considerations

Considering the ethical aspects is a crucial point when it comes to conducting social science research. Research ethics rotate around practices that involve confidentiality and privacy, harm and deception, and gain informed consent.

Prior to commencing, the researcher conducted an intensive assessment of the suggested investigation against the University of Sheffield Ethics Policy '*Ethics Policy Governing Research Involving Human Participants, Personal Data and Human Tissue*' (University of Sheffield, 2016) as the academic host foundation. Ethical approval request was applied for and subjected to formal scrutiny by the University of Sheffield, School of Architecture Ethics Committee.

The researcher has considered some essential ethical aspects including:

- The online questionnaire: the potential participants will be contacted directly by sending them an email, or in some cases might require contacting the participants indirectly, through their practices or organisations based on Snowballing technique. The email will include an invitation/information letter and the web link to the online questionnaire. Once the potential participants show their interest to take part in this study, a digital consent form will be shown on the first of the online questionnaire interface, asking them to tick all the field that they agree to participate in this study in the consent form to get formal approval of them.

- Potential Harm to participants: there is no such expected harm (i.e., physical and/or psychological harm/distress) as the questions of the questionnaire will not be personal in nature or sensitive and will be explicitly pertinent to the BIM adoption at the organisation level. Almost all the questions are in the form of statements to either agree or disagree with them based on 5-point Likert Scale.
- Data Confidentiality Measures: the confidentiality of personal data in this research will be achieved using identifiable personal information will be reduced as far as possible. All information that is collected about the participant or organisation during this project will be kept strictly confidential. In this sense, in the questionnaire, the data will be collected and accumulated anonymously without referring to the names of the participants of their organisations.
- Data Storage: according to Research Ethics Policy Note no. 4: Principles of Anonymity, Confidentiality, and Data Protection, the data will be stored securely by the researcher in his computer database by using a password to access the data. Printed versions will be maintained in a locked cabinet. After completion of PhD, the data could be used for future research (approximately for five years). For this reason, the consent form includes a request for participants agreement on this issue. If no agreement is given, the corresponding data will be destroyed after the completion of PhD.

Having been reviewed with no ethical issues were raised, this study has received ethical approval from the Sheffield School of Architecture, University of Sheffield.

4.11 Summary

This chapter has discussed and identified the adopted philosophical and methodological approaches. This research is a retrospective and cross-sectional survey study that predominantly falls into the class of explanatory research and secondarily within descriptive research. It combines cycles of deductive and inductive reasoning approaches. The research philosophy is positivism that presumes an objective reality exists. The research strategy is mainly quantitative, and it used two questionnaires surveys for empirical research. The first questionnaire is the main technique for collecting the primary data of Phase 2, and the second questionnaire survey will be devised for conducting the F-DEMATEL of Phase 3 in Chapter Eight. Finally, the ethical considerations applied to this study were demonstrated.

This chapter will inform and guide this study as demonstrated in the following chapters.

Chapter 5 | Development of a Unified BIM Adoption Taxonomy (UBAT) and BIM Adoption Process Conceptual Model

5.1 Introduction

This chapter aims to achieve *Objective 2* of this study:

"*To develop and validate (1) a unified BIM adoption taxonomy of drivers and factors and (2) a conceptual model to guide the empirical investigation of the BIM adoption process*" (Ahmed and Kassem, 2018, p.103).

"This will allow conducting a retrospective analysis of BIM adoption within a market (i.e. the United Kingdom) by considering a sample of organisations that have already confirmed BIM (i.e., in the next chapter). This chapter comprises six main sections. Section 5.2 demonstrates the key terms and concepts explaining the diffusion of innovation processes. Section 5.3 proposes a Unified BIM Adoption Taxonomy (UBAT) in the form of three hierarchical taxonomy levels (i.e., clusters) covering drivers, factors and determinants of BIM adoption. Section 5.4 describes the BIM Adoption Taxonomy constructs (i.e., 17 factors). Sections 5.5 and 5.6 empirically evaluate and validate the measurement models that represent the taxonomy's constructs which are developed in the form of Structural Equation Modelling (SEM). Finally, a conceptual model for the empirical investigation of the BIM adoption process within organisations is developed" (Ahmed and Kassem, 2018, p.111) in Section 5.7.

Figure 5.1 shows a roadmap of Chapter 5 in achieving Objective 2 of the study.

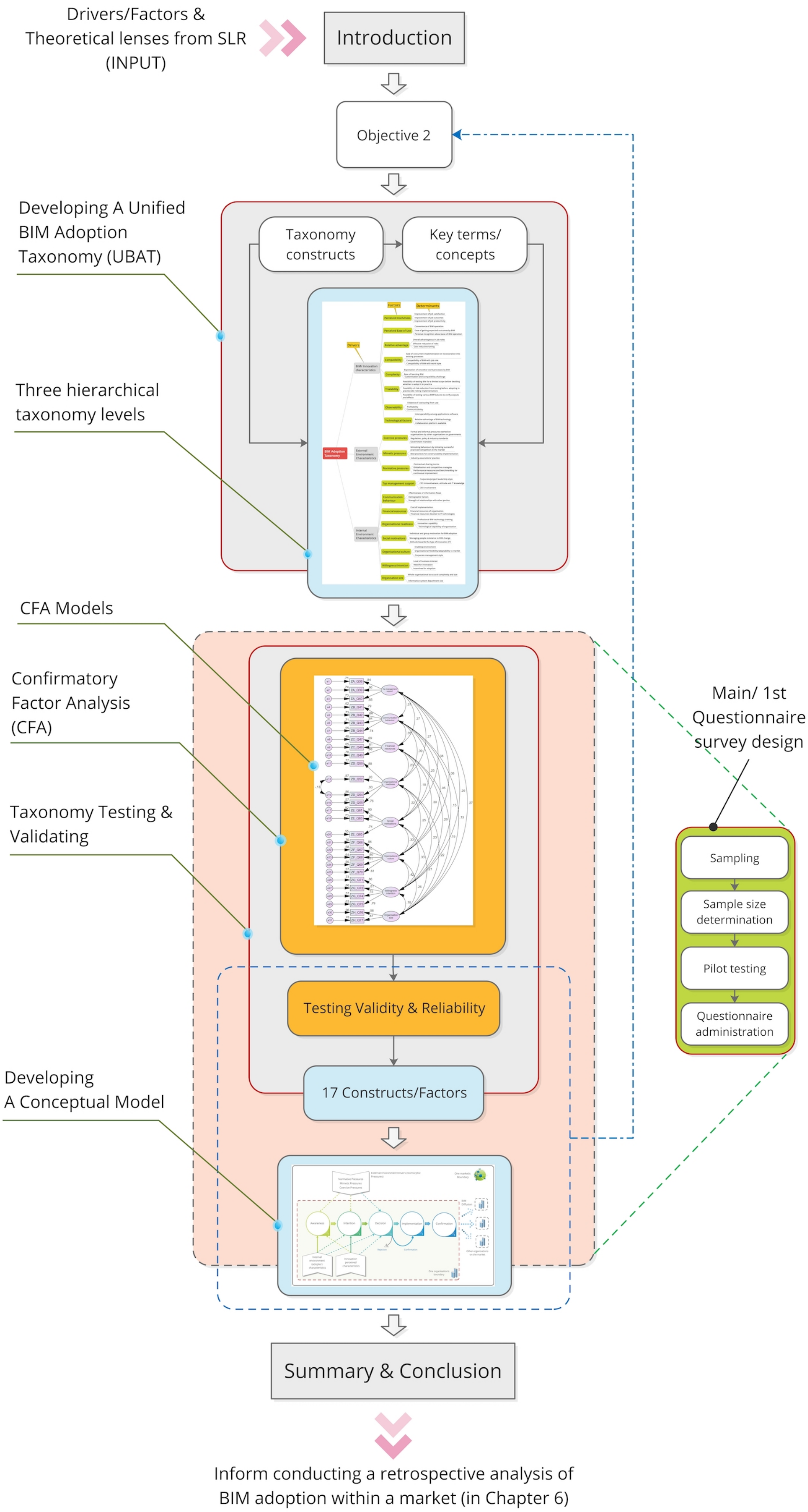


Figure 5.1 A roadmap of Chapter 5 in achieving Objective 2 of the study

5.2 Key Terms and Concepts of the taxonomy

In this section, the most widely used key terms and concepts explaining the diffusion of innovation processes are demonstrated. It is recognised that linguistic connotation is greatly context-dependent, and therefore, it showed difficult to hold to such concepts as 'technology transfer', 'organisation', 'innovation', 'diffusion', 'spread', as in practice different researchers used words in specific contexts. Similarly, with the other wide range of critical terminologies such as 'adoption', 'implementation', and 'communication' (Greenhalgh et al., 2008; Tidd, 2010). "This study investigates BIM adoption at the organisational level and pertinent market-wide adoption aspects. Several of the terms used across this scale of investigation may have competing or complementary definitions. This section clarifies the main terms used throughout the study after briefly illustrating some of their existing interpretations" (Ahmed and Kassem, 2018, p.104):

- "[**Innovation**: The term refers to "*an idea, practice, or object that is perceived as new by an individual or other unit of adoption*" (Rogers, 2003, p.457). Within an 'organisational' context innovation can be understood as "the development and implementation of new ideas by people who over time engage in transactions with others within an institutional order" (Van de Ven, 1986, p.590), and "the implementation of an internally generated or a borrowed idea – whether pertaining to a product, device, system, process, policy, program or service – that was new to the organisation at the time of adoption" (Damanpour and Gopalakrishnan, 1998, p.392). These complementary definitions are suitable for this study purpose which adopts the definition of BIM as the current expression of digital innovation in the construction sector (Succar and Kassem, 2015)]" (Ahmed and Kassem, 2018, p.104).
- "[**Adoption vs. Implementation**: a universal agreement on the definitions of these terms is lacking in the literature. Adoption and implementation are often used interchangeably [as in(Al-Shammari, 2014), (Haron et al., 2014), (Wu and Issa, 2014), (Attarzadeh et al., 2015), (Ding et al., 2015), and (Hosseini et al., 2015)]. This blurs the distinction between interrelated concepts such as adoption, implementation, and diffusion. Rogers (2003, p.456) defines

‘adoption' as “*a decision to make full use of an innovation as the best course of action available*” and ‘Implementation' as that phase which occurs once an innovation has been put into use (Rogers, 2003, p.457). In Rogers's Innovation-Decision Process, ‘adoption’ is one of the two outcomes (i.e. adoption, and rejection) of Stage 3 (i.e., decision stage). Succar and Kassem (2015) define BIM adoption as the successful implementation whereby an organisation, following a readiness phase, crosses the ‘Point of Adoption' into one of the BIM capability stages, namely modelling, collaboration and integration. Moreover, the authors propose to overlay the connotation of both ‘implementation’ and ‘diffusion’ unto the term ‘adoption’ within the context of macro (i.e., market-wide) adoption. These varying definitions indicate that ‘adoption’ could be considered as a more holistic term than ‘implementation’, which refers to either a specific phase (e.g.,Rogers, 2003) or a milestone (e.g.,Succar and Kassem, 2016). Although this study adopts Rogers's multi-stage Innovation-Decision Process due to its explicit itemisation of the first three stages (i.e., awareness, intention, decision) preceding adoption decisions, it recognises the need for a more holistic definition of the term ‘adoption’ as proposed in Succar and Kassem (2015)]” (Ahmed and Kassem, 2018, p.104).

- “[**Diffusion Dynamics**: Combination of directional mechanics (i.e., Downward, Upward and Horizontal) and isomorphic pressures (i.e., Coercive, Mimetic and Normative) that allow innovation to contagiously pass from ‘transmitters’ to ‘adopters’ (Succar and Kassem, 2015)]” (Ahmed and Kassem, 2018, p.104).
- “[**Macro-Meso-Micro**: analytical levels (Dopfer et al., 2004) or clusters of organisational scales (Succar, 2010). The *Macro cluster* includes subdivisions, sectors, industries and specialities at market-wide level. *Meso cluster* includes project-centric organisational teams that are aggregated at a project level; and the *Micro cluster* includes individuals and groups at an organisational subdivision level]” (Ahmed and Kassem, 2018, p.104).

5.3 The BIM Adoption Taxonomy

Having conducted the Systematic Literature Reviews (in Chapter Three), "the BIM adoption taxonomy emerged as a result of this study's investigation of RQ1 (i.e. what are the drivers and factors affecting the decision to adopt BIM at organisation level within the construction industry?); and RQ2 (i.e. what are the theories, frameworks, and models adopted by scholars for examining BIM/innovation adoption and diffusion in construction?). The hierarchical taxonomy has three levels covering drivers, factors and determinants of BIM adoption" (Ahmed and Kassem, 2018, p.106) (Figure 5.2).

"The first level of the taxonomy identifies three *driver* clusters: the *BIM innovation characteristics*; the *external environment characteristics*, and the *internal environment characteristics*. The three clusters are further expanded at the second and the third level of the taxonomy that establish respectively the adoption *factors* within each driver cluster and the *determinants* representing the different manifestations of each factor. The first cluster, the *BIM innovation characteristics,* includes eight factors (i.e., constructs), namely: perceived ease of use, perceived usefulness, relative advantage, compatibility, complexity, trialability, observability, and technological factors. The second cluster, the *external environment characteristics,* includes three factors, namely: coercive pressures, mimetic pressures, and normative pressures. The third cluster, *internal environment characteristics*, includes eight factors, namely: top management support, communication behaviour, financial resources, organisational readiness, social motivations, organisational culture, Willingness, and organisation size. However, 17 out of the 19 constructs will be considered and tested. Two constructs (i.e., perceived usefulness; and perceived ease of use under the BIM innovation characteristics) were excluded from the BIM Adoption Taxonomy since their effect, according to the innovation adoption literature (Davis, 1989; Abdul Hameed, 2012; Xu et al., 2014), exert at the implementation stage after the adoption decision has been made (i.e. stage 4 in: awareness, interest, decision, implementation, and confirmation) while the survey questions were focussed on analysing the adoption process up to decision stage" (Ahmed and Kassem, 2018, p.106).

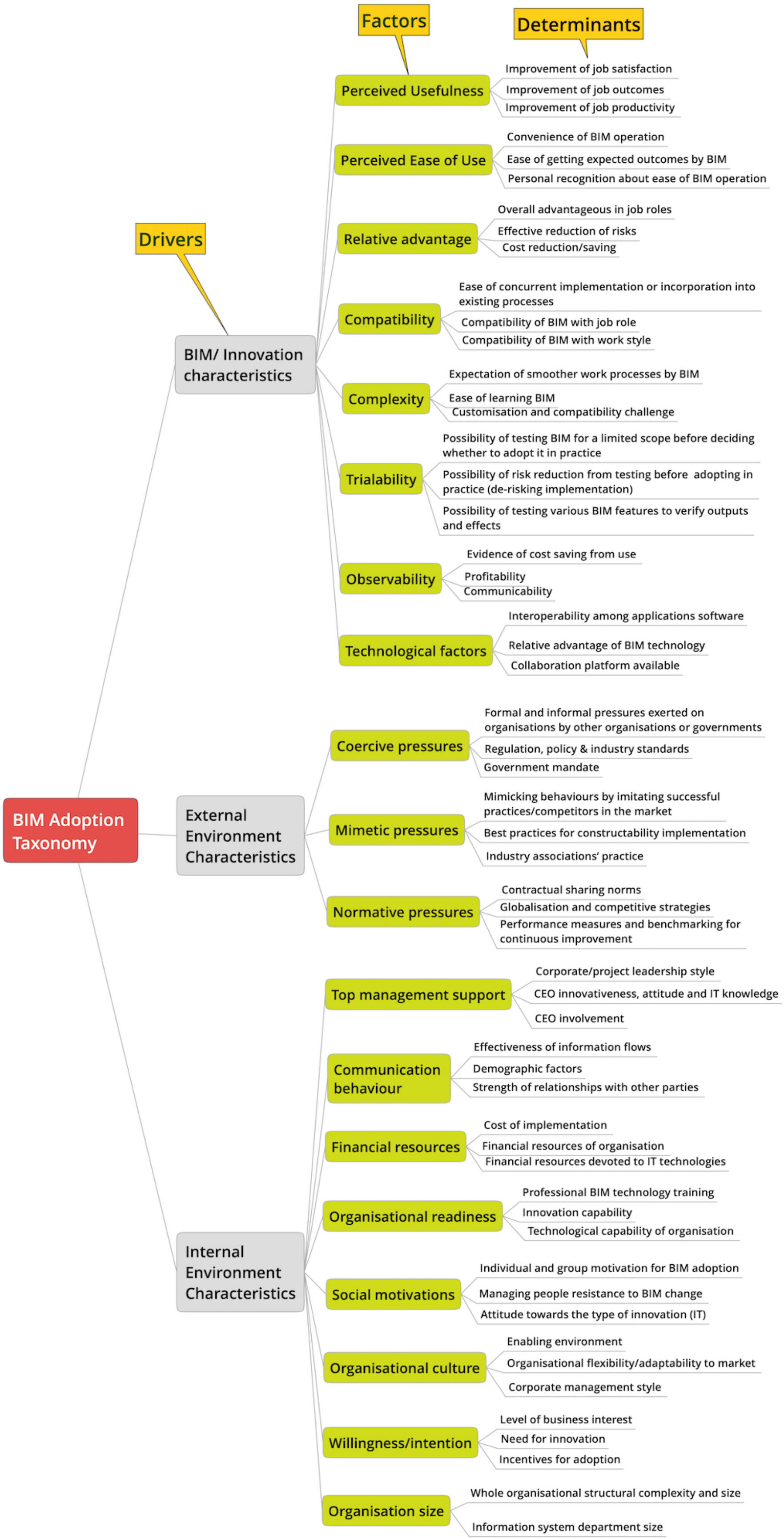


Figure 5.2 The Proposed BIM Adoption Taxonomy

5.4 BIM Adoption Taxonomy Constructs: Overview

In the following section, all the identified 17 factors/constructs of the BIM Adoption Taxonomy will be reviewed through examining the prior literature on how the innovation (e.g., BIM and ICT/IS innovations) adoption by organisations was influenced by these constructs.

5.4.1 The constructs of the External Environment characteristics

5.4.1.1 Coercive pressures

Coercive pressures refer to the formal and informal forces applied to organisations by other organisations upon which they are reliant (DiMaggio and Powell, 1983, p. 150). Coercive pressures are one of the "three isomorphic pressures (i.e., coercive, mimetic, and normative pressures) of the Institutional Theory" (Ahmed and Kassem, 2018, p.108) which is developed by DiMaggio and Powell (1983). Such pressures drive companies to adopt similar organisational procedures and practices (Teo et al., 2003). These legitimacy-based motives (i.e., coercive pressures) stem from institutions in an organisation's environment that directly formulate policies which an organisation requires to comply with, and to be authoritative enough to specifically recompense obedience or sanction non-compliance (Krell et al., 2016). These institutional pressures can affect organisational structure, environment, and behavioural attention (DiMaggio and Powell, 1983); and drive an organisation to conform to institutional and political legitimacy to secure its existence in a social network (Tsai et al., 2013). Such institutions exert their authority to impose companies to involve in certain activities and thus, they directly enforce restrictions on firms (Oliver, 1991). Organisations that exercise coercive pressure include, for instance, clients who purchase huge shares of a company's production, providers of scarce resources, and government and regulatory bodies (Xue et al., 2008; Wong et al., 2009; Sherer et al., 2016). Liu et al. (2010a) argue that as a dominant network member favours an innovation (e.g., eSCM), this member might coercively drive its partners to adopt the innovation. In this procedure, a dependent organisation would first sense coercive forces that point out to the asymmetry of strength and then better realise the results of adopting or not adopting the innovation (i.e., eSCM). Conflicting with the powerful organisation's desires may risk the dependent firm's existence owing to its reliance on the powerful partner. Hence, the dependent firm has the tendency to conform to the powerful partner's demand and be willing to adopt the innovation. Accordingly, the organisation with a control orientation would probably adopt the innovation. Also, when an organisation recognises a high degree of coercive pressures, its powerful partner/client allocates individuals of the community to organise activities of the supply chain. Contrasted with its low control orientation counterparts, an organisation that has a high control orientation is more likely to appreciate the excessive implementation benefits that formulate a more favourable attitude toward the innovation adoption. Due to the potential advantages of BIM, governments (or their affiliated agencies) in many countries have set up plans for the compulsory utilisation of BIM in public projects. These legitimate exercises, regardless of whether as public regulation or project- specific prerequisite, may essentially impact the BIM adoption behaviours of both venture customers/owners and different stakeholders, and accordingly result in a more noteworthy degree of undertaking BIM utilisation (Cao et al., 2014).

5.4.1.2 Mimetic pressures

Mimetic pressures essentially result from an organisation's observed success of competitors' activities (DiMaggio and Powell, 1983). Mimetic pressures are described as the forces that are derived from behavioural uncertainty on how to tackle a particular issue, achieve a specific action or attain a specific aim (Krell et al., 2016). Due to this ambiguity/uncertainty, an organisation (i.e., firm) imitates behaviours executed by an apparently successful organisation within the organisation's environment (Oliver, 1991). In this regard, 'uncertainty' occurs when a firm has inadequate information to tackle a problem. Hence, the firm perceives that organisations in its atmosphere have positively tackled similar problems (Krell et al., 2016) and, therefore, inclines to benchmark its behaviour against that of peer firms. Consequently, it imitates organisations that seem legitimate and progressive (DiMaggio and Powell, 1983; Succar and Kassem, 2015). Typically, organisations' decision-makers consider that a behaviour of other comparable organisations is simple to mimic as the chance of benefit appears higher if such behaviour was effectively performed previously. Thus, companies are probably to imitate organisations that either perform in comparable markets, utilise similar assets, or offer comparable products (Teo et al., 2003). Consequently, behaviours performed by comparable firms are seen to be suitable for a firm that takes part in mimicry (DiMaggio and Powell, 1983). According to a study by Cao et al. (2014), the significant positive statistical correlation was concluded between the mimetic pressures and BIM adoption decision. This conclusion stems from the nature of BIM as an innovation comparing to other innovations. BIM applications normally contain more complicated process and organisational exchange in construction projects (Eastman et al., 2011). Also, BIM involves fairly high venture/investing cost (Bryde et al., 2013). Such attributes may significantly increase the BIM adoption uncertainties and, consequently, enforce firms' decision-makers to be more effectively impacted by the direct behaviour of counterpart organisations of similar attributes and institutional atmospheres. Hence, every owner of a project and other stakeholders could be exposed to such effect. Clients/owners usually imitate the successful activities in counterpart organisations to better risk-averse against the pertinent dangers which are partially accepted by the first adopters. By doing this, those clients will not fall behind their counterparts and, therefore, will not lose their legitimacy (Cao et al., 2014). Some previous research on other construction innovations [e.g., (Esmaeili and Hallowell, 2011; Kale and Arditi, 2005; Nikas et al., 2007)] has also inspected the impact of mimetic pressures on the intentions and behaviours of innovation adoption decision, which have concluded relatively contradictory findings. The variations in the nature of such innovative practices may provide reasonable clarification for these conflicting results. Regarding radical and complicated innovations (e.g., BIM), the adoption decision process usually entails not only organisational restructuring, relatively high investing cost, and intangible advantages, but may also apply significant social effect due to the extensive industry enthusiasm in the innovations. Contrasted to other innovations with a lower return on investment (ROI) and social impact and uncertainty, the adoption decisions about those innovations incline to become extra effortlessly affected through the behaviours of peer competitors (Cao et al., 2014).

5.4.1.3 Normative pressures

Normative pressures are the forces originated from the values and shared norms among individuals of a network, professionalisation, and collective desires within specific organisational contexts in which constitute suitable and legitimate behaviour (DiMaggio and Powell, 1983; Heugens and Lander, 2009; Scott, 2013). These behaviours and beliefs can be diffused and fortified across the professional domains over knowledge transfer activities (e.g., formal learning, industry associations, conference interaction, and professional sessions and workshops) (DiMaggio and Powell, 1983). The difference between normative pressures and coercive pressures that is the organisations of which exert normative pressures are powerless to directly impose (i.e., less compelling mode) compliance and sanction non-compliance (DiMaggio and Powell, 1983; Teo et al., 2003). Subsequently, normative pressures do not influence organisations through intimidation, rather, organisations conform to norms as decision-makers recognise themselves with specific industrial and professional foundations (Krell et al., 2016). Therefore, those decision-makers consider such compliance with common norms identified by the professional and industry organisations is valuable for their own organisation (Palmer et al., 1993). Being surrounded with such professional domains, firms may progressively improve their perceptions of the generally diffused beliefs and values, and hence, alter their actions based on their particular organisational features (Cao et al., 2014; Henderson et al., 2012; Liu et al., 2010a). In the context of BIM adoption, technology vendors, industry professionals, and universities can also exert normative forces on industry practitioners across various networks such as industrial conferences, formal education, and professional accreditation. As important decision-makers on BIM adoption in construction ventures, owners/clients may turn into possible pivotal factors of such normative pressures. Those clients/owners, through collaborations with the experts, may better recognise the beliefs and industry expectations concerning the BIM implementation in their particular activities. Therefore they exert additional support for BIM adoption. This support, alongside with the altered behaviours and attitudes of other project contributors - who might also be immediately exposed to external normative pressures - would lead to a better extent of BIM adoption (Cao et al., 2014).

5.4.2 The constructs of BIM innovation characteristics

5.4.2.1 Relative advantage

Relative advantage "["refers to the degree to which an innovation is perceived as being better than the previous idea" (Rogers, 2003, p.229), and the anticipated benefits, or perceived profits offered by the innovation to an organisation (Moore and Benbasat, 1991; Chwelos et al., 2001a; Rogers, 2003)]" (Ahmed and Kassem, 2018, p.106). Relative advantage is proposed by Rogers (2003) and recognised as the main determinant explaining the innovation adoption (i.e., IS technologies) (Henderson et al., 2012; Tsai et al., 2010; Oliveira et al., 2014) and most precise predictor that plays significant role in measuring the rate of innovation adoption (Seed, 2015; Tsai et al., 2010). It is a key characteristic that determines whether an innovation (e.g., BIM or ICT) is relatively advantageous through the estimated benefits (Oliveira et al., 2014), and influences the organisation's behavioural intention to adopt an innovation (Tsai et al., 2010). Rogers (2003) argues that the nature of the innovation defines which the important kind of relative advantage (e.g., economic benefit and social position) to the potential adopter. Prior studies on innovations in the ICT/IS field have found that relative advantage positively influences the innovation adoption (e.g., Oliveira et al., 2014; Ifinedo, 2011; Tan and Ai, 2011; Wang et al., 2010). However, other studies suggested that the relative advantage of some innovations is not decisive across industries. Such studies, recognised concerns for example: hidden costs, needs of human resource for promotions and maintenance, probable loss of general control of assets, and the poor quality of the process of the elements influence the relative advantage of innovations (Lee and Mautz Jr, 2012; Lin and Chen, 2012; Low et al., 2011). Hence, the relative advantage will act as an inhibitor to innovation adoption (Oliveira et al., 2014). In the context of BIM adoption, the positive influence of relative advantage appears in the form of, for example: economic/financial benefits (i.e., cost saving), marketing aspects (i.e., BIM adoption supports firm marketing) (Seed, 2015); use of 4D BIM for sharing the construction plan (Gledson and Greenwood, 2017); and support to various activities and processes across the AEC industry (Kim et al., 2015). Thus, relative advantage can indicate the extent to which current work execution is anticipated to be enhanced by adopting BIM (Kim et al., 2015; Rogers, 2003; Azhar et al., 2011; Bryde et al., 2013).

5.4.2.2 Compatibility

Compatibility can be defined as "the degree to which an innovation is reliable with potential adopter's current values, previous experiences, and present needs" (Rogers, 2003, p.240). Many studies on organisational adoption of ICT/IS indicated that compatibility is a key factor of an innovation adoption [e.g., (Azadegan and Teich, 2010; Chong and Bauer, 2000; Dedrick and West, 2004; Mijinyawa, 2011; Sila, 2010)]. For example, the compatibility of certain innovation (e.g., cloud computing) with current business processes provides a relative advantage to the organisation/potential adopter (Oliveira et al., 2014). Prior studies, also, have found that the compatibility between the new innovation/technology and the organisations' existing work experience and responsibilities (Rogers, 2003) will increase the 'behavioural intention' to adopt the innovation through increasing the "perceived usefulness and the ease of use of the innovation (Kishore and McLean, 2007; Kuo and Lee, 2011; Shih, 2008; Thong, 1999; Wu and Wang, 2005; Wu et al., 2007)" (Ahmed and Kassem, 2018, p.106). In the domain of BIM adoption, similarly, compatibility was recognised as a critical factor affects the potential adopters' behavioural intention to adopt BIM (Kim et al., 2015; Gu and London, 2010; Son et al., 2015; Davies and Harty, 2013; Gledson and Greenwood, 2017; Xu et al., 2014). Davies and Harty (2013) suggest that BIM is perceived to enhance business performance and functions when it is compatible with the current workflows and process, and hence, suggests compatibility as a prerequisite of BIM adoption by organisations. In this regard, the interoperability of BIM technology that enables information exchange among various BIM platforms can be considered as software compatibility (Eastman et al., 2011). Thus, lack of such interoperability creates an impediment to achieving successful adoption of BIM by organisations (Liu et al., 2010b).

5.4.2.3 Complexity

Complexity, according to Rogers (2003, p.257), "[is "the degree to which an innovation is perceived as difficult to understand and use"]" (Ahmed and Kassem, 2018, p.106). It is identified as one of the important innovation characteristics that affect the organisation's adoption intention (i.e., the behavioural intention) of an innovation (Tsai et al., 2010). Complexity, together with relative advantage and compatibility, are considered as essential indicators and predictors while assessing the benefits and difficulties of new technology innovation (Tsai et al., 2010; Tornatzky and Klein, 1982). The complexity of innovation can be multifaceted (Gopalakrishnan and Damanpour, 1994). It may cause an intellectual struggle related to understanding innovation as in the disparities between low-tech and high-tech innovations (Drucker, 1985; Gopalakrishnan and Damanpour, 1994). It can also reflect the originality (the level of novelty) of an innovation (Rogers, 2003). The innovation which is more challenging to be implemented and less trialable is less likely to be adopted by organisations due to the greater uncertainty of its success and the lower chance of its involvement in enhancing organisational performance (Gopalakrishnan and Damanpour, 1994; Rogers, 2003). Complex innovation entails additional skills in handling the adoption process, including making an atmosphere for innovation, incorporating the innovation into existing organisational procedures, sustaining an awareness of insistence to allow effective implementation, and overcoming conflict to innovation and expediting its usage by organisational individuals (Damanpour and Schneider, 2006; Daft et al., 2010). As the complexity indicates the extent of difficulty to use an innovation, which leads to some uncertainty, prior research has found that complexity is an inhibitor to the adoption of an innovation (e.g., ICT/IS) by organisations (e.g., Oliveira et al., 2014; Tsai et al., 2014; Henderson et al., 2012; Attewell, 1992; Chau, 1996). Similarly, prior research on BIM has concluded the negative effect of BIM complexity on its adoption by organisations (e.g., Kim et al., 2015; Xu et al., 2014; Rogers et al., 2015; Ahuja et al., 2016). Hence, the simpler it is to incorporate the innovation into business activities, the more contingent of being adopted by organisations (Oliveira et al., 2014).

5.4.2.4 Trialability

Trialability refers to “the degree to which an innovation can be experimented with on a limited basis” (Rogers, 2003, p.258). Also, it provides the opportunity to experiment with innovation before determining on the approval or disapproval of the innovation (Venkatesh and Davis, 2000; Kumar and Swaminathan, 2003). Such trial indicates the ease of testing the new innovation by the potential adopter (Oliveira et al., 2014). Prior studies on ICT/IS innovations have found that trialability is positively influencing the process of the innovation adoption [e.g.,(Hameed et al., 2012; Henderson et al., 2012; Tornatzky and Klein, 1982)]. Similarly, in the field of BIM adoption, enormous studies [e.g., (Kim et al., 2015; Ahuja et al., 2016; Gledson and Greenwood, 2017)] have proposed that trialability is an important factor that facilitates the BIM adoption decision. An additional value of trialability is the chance to inspect the distinctive advantages of BIM without prejudice and subjecting the firm’s bottom-line at risk (Panuwatwanich and Peansupap, 2013). Furthermore, the innovation trialability decreases uncertainty and inclines to enhance the rate of adoption (Ahuja et al., 2016). For example, trialability provides the intention to experiment BIM in a restricted extent; probability of risk reduction through trying-out BIM prior to its adoption decision by potential adopters; and the intention to check BIM effects on the firms’ performance by testing its features (Kim et al., 2015). However, trialability as an adoption factor is challenged by lack of social practice that promotes sharing of benefits and experience of BIM implementation among potential adopters (Panuwatwanich and Peansupap, 2013; Kim et al., 2015).

5.4.2.5 Observability

Observability, according to Rogers (2003, p.258), is “[“the degree to which the results on an innovation are visible to others”]” (Ahmed and Kassem, 2018, p.106). Also, it is the extent to which the outcomes of adopting an innovation are obvious and well conveyed (Greenhalgh et al., 2005). Many previous research on ICT/IS innovations has indicated that observability and trailability are significant factors that affect innovations adoption (e.g., Cope and Ward, 2002; Martins et al., 2004; Groff and Mouza, 2008). However, other studies have concluded relatively contradictory findings (e.g., Hameed et al., 2012; Chong et al., 2009; Oliveira et al., 2014). A number of studies on BIM adoption have also concluded similar contradicted findings (e.g., Seed, 2015; Kim et al., 2015). For instance, Seed (2015) argues that BIM advantages are difficult to be observed, and hence, observability does not have any influence on the adoption of BIM by organisations in the UK construction industry. This is because of the reluctance of sharing what may be considered as confidential and sensitive financial information within a competitive market. Also, the hesitance of voluntarily endorsing to adopt BIM due to the poor demonstration of BIM influence in the AEC industry is considered as a barrier (Kim et al., 2015). BIM observability measurement may include, for example, the support of publicity of the positive impacts of BIM; the clear perception of the positive impacts of BIM; and the intention to endorse BIM to potential adopters (Kim et al., 2015; Seed, 2015).

5.4.2.6 Technological factors

Technological factors indicate the perceived attributes of the innovation to be adopted (Depietro et al., 1990). Rogers (2003) recognises technological characteristics – together with social systems and communication channels – as one of the important factors influencing the innovation adoption. Based on Doolin and Troshani (2007) study approach, Henderson et al. (2012) argue that the technological factors are derived from the "Innovation Diffusion Theory and comprise relative advantage, complexity, trialability, compatibility, and observability" (Ahmed and Kassem, 2018, p.113). These factors affect the potential adopters' beliefs in making rational decisions to adopt a new technology based on the adoption view of benefits/cost. Similarly, Peansupap and Walker (2005a) investigated the technological factors (i.e., relative advantage, compatibility, and ease of use) effect on the individuals' adoption decision of a new innovation (i.e., ICT). The influence of these factors measured by the supporting technology characteristics, and frustration with ICT use are determinants affecting the innovation adoption. On the other hand, previous innovation studies (e.g., ICT and BIM) have focused not only on the non-physical factors but also on the physical ones (Young et al., 2009; Husin and Rafi, 2003; Gu and London, 2010). For instance, equipment and infrastructure capacity factors (Husin and Rafi, 2003; Young et al., 2009); BIM-based collaboration platform within the AEC disciplines (Singh et al., 2011; Gu and London, 2010; Seed, 2015); software applications interoperability (Xu et al., 2014); and BIM software availability and affordability (Abubakar et al., 2014).

5.4.3 The constructs of the Internal Environment characteristics

5.4.3.1 Top management support

Top management support is "the degree to which senior management understands the importance of the information systems function and the extent to which it is involved in IS activities" (vom Brocke, 2007, p. 213). In previous literature, top management support is recognised as one of the factors that critically influence the adoption and implementation of information technology and information systems innovations (Thong et al., 1996; Swink, 2000; Madanayake, 2014). In many BIM studies, top management support was cited as a key factor influencing in BIM adoption (Liu et al., 2010b; Hartmann et al., 2012; Son et al., 2015). According to Arayici et al. (2011a), top management support is essential for achieving the success of the BIM adoption. Also, top management support was identified to play a critical role affecting the behavioural intentions of the architectural firms towards BIM adoption (Son et al., 2015). Top management support warrants sufficient provision of resources and integration of services (Lucas Jr, 1978; Ngai et al., 2008; Thong et al., 1996), and affect the organisation's members to implement the change in business processes (Oliveira et al., 2014; Ahuja et al., 2016). It has the power to make a more encouraging environment for IT innovation implementation, thus facilitating the adoption of the innovation (Thong et al., 1996). Additionally, top management support rises employees' perceptions of innovation/system usefulness (Lin, 2010; Son et al., 2012). Lack of top management support and their fail to recognise the benefits of the new innovation to their business, they will be opposite to its adoption (Oliveira et al., 2014).

5.4.3.2 Communication behaviour

According to Rogers (2003), communication behaviour is one of the most important characteristics of adopter categories (i.e., innovators, early adopters, early and late majority, and laggards) of innovations. Communication behaviour explains the interaction activities (Connectedness) among the members of a social system through communication channels (interpersonal networks). Rogers (2003) adopters categories take different forms of communication behaviour. The interpersonal networks of the innovators are usually to be outside their system rather than inside it. The innovators travel broadly and are involved in activities beyond the borders of their local system. *Earlier adopters* and *Later adopters*, exhibit significant differences. Earlier adopters show more social involvement; more greatly interconnected in the interpersonal channels of their system; more cosmopolite; more interaction with change mediators; more exposure to mass media networks; greater exposure to interpersonal communication channels; more involvement with effective information seeking; and have more knowledge of innovations and a higher level of views leadership. In construction organisations, the communication behaviour "can be either formal/ intra-organisational communication (e.g., working colleagues interacting inside the same division), or informal/ inter-organisational communication (e.g., like-minded individuals of other organisations meeting up and sharing good examples of practice for their individual mutual advantage) (Murray et al., 2007)" (Ahmed and Kassem, 2018, p.112). Intensive clustering of individuals has a deep effect on innovation within organisations and shaping whether the new processes or innovation will be adopted by the others (Albrecht and Hall, 1991). Therefore, communities of practice become organisationally more useful to the invention and adoption of new notions (Wenger et al., 2002). Furthermore, "effectiveness of information flows (communication flows) within organisations; strength of relationships with other parties (clients, governments, labour unions) (Mom et al., 2014); learning from external sources (Henderson et al., 2012); and interactions between individuals and organisations within the construction industry and between the industry and external parties (Blayse and Manley, 2004; Gorse and Emmitt, 2007), are examples of communication behaviour applications for adopting BIM/IT innovation" (Ahmed and Kassem, 2018, p.112).

5.4.3.3 Financial resources

Financial resources are "*the money available to a business for spending in the form of cash, liquid securities and credit lines*" (BusinessDictionary.com, 2018). It is "*the degree to which financial resources are available to the project*" (von Stamm, 2008, p. 384). The previous literature of BIM/innovation adoption within organisations has asserted on the necessity to perform an initial evaluation of the financial resources of an organisation (Gledson et al., 2012; Mom et al., 2014; Ding et al., 2015) to identify the requirements of successful implementation (Gledson et al., 2012). In the process of BIM adoption, combining factors of technology implementation and decision-making entails assessing the financial resources of the firm (Mom et al., 2014). Control of considerable financial resources is useful in retaining the conceivable losses from an unfruitful innovation (Rogers, 2003). In this regard, Webster Jr (1969) refers to the sign of the financial strength of a firm based on the early adopters who can best afford the risk related to the adoption of new innovation. Indeed, a specific level of financial resources risk occurs for investing in hardware and software related to adopting BIM which additionally forms requests of staff preparing and training (Love et al., 2011). Devoting the financial resources (e.g., capital, operational, and maintenance budget) to adopt an innovation (e.g., IT/IS technologies) refers to the organisational readiness – as adopter characteristics - to invest resources in organisational innovation (Waarts et al., 2002; Tsai et al., 2010; Lynch, 2007). Meyer and Goes (1988) suggest an adoption-decision stage in which the evaluation to accept a potential adoption of innovation from a financial, technical, and strategic aspect. This involves allocating suitable financial resources for acquisition and implementation (Hameed et al., 2012). At the earlier stages of BIM adoption showed that unless the awareness and interest of importance of BIM technology supported with financial resources, the implementation of BIM would not be easy (Ding et al., 2015). In Architectural firms, BIM requires a high arrangement budget to initiate BIM implementation in architectural projects. The budget can be divided into 'one-off setup cost' and 'general system-related cost' (Ahuja et al., 2016). The one-off setup cost represents all the expenditures essential for delivering the technical aspects and organisational solutions (Bouchbout and Alimazighi, 2008). While general system-related cost represents all the expenditures relating to the assembly of the system and the organisation preparation into the BIM process. Generally, it is perceived that innovations with lower financial expenses are more likely to be adopted by organisations (Ahuja et al., 2016).

5.4.3.4 Organisational readiness

Organisational readiness is "a multi-level and multi-faceted construct" refers to organisational individuals' mutual resolve to perform a changing duty and mutual belief in their aggregate capacity to achieve such (change efficiency)(Weiner, 2009, p. 67). According to Succar and Kassem (2015), organisational readiness is the phase of preparation and planning prior to the point of adoption when an organisation adopts initial BIM capabilities. The 'readiness' points to whether a firm is prepared to embrace BIM innovation (Mom et al., 2014). Achieving a successful adoption of an innovation is contingent on a firm's proactive arrangement for the innovation (Tsai et al., 2013; Iacovou et al., 1995). Prior research has identified *Organisational readiness* as a key critical success factor for IT/ innovation adoption intention (Mom et al., 2014; Tsai et al., 2010). For example, Tsai et al. (2013) examined three elements of the organisational readiness: technological expertise, support from senior management, and financial resources. Premkumar and Ramamurthy (1995) studied IT infrastructure, innovation champion, and top management support. Also, there are other organisational readiness characteristics that are most frequently investigated in IT adoption studies: centralisation, firm size, formalisation, specialisation, and complexity (Lai and Guynes, 1997; Premkumar and Ramamurthy, 1995; Premkumar and Roberts, 1999; Shim et al., 2009).

5.4.3.5 Social motivations

Social motivation is "an incentive or drive resulting from a sociocultural influence that initiates behaviour towards a particular goal" (Puri and Abraham, 2004, p. 297). Cao et al. (2016) investigated how different social motivations (i.e., proactive image motives, and reactive motives) positively affect BIM implementation processes within organisations comparing with economic motivations. Image motives maintain the decent image of implementing advanced technologies, while reactive motives passively conform with the external environment (e.g., complying with BIM needs from governments, and promising to enhance competitiveness by employing BIM). BIM as a socialised innovation process (Cao et al., 2014; Succar and Kassem, 2015) can be relatively complicated due to the influences of the institutional pressures. Thus, social motivations and organisational awareness are jointly turned into – by the external pressures – a critical factor formulating the adoption and implementation processes (Cao et al., 2016). Social motivations were frequently recognised as a critical factor in technology adoption decision by organisations (Singh and Holmstrom, 2015). Carley and Behrens (1999) consider that organisational adoption decision is a result of combining both how the individuals make decisions and their context in which these decisions are taken. A study by Javernick-Will (2012) described the key role and power of social motivations in sharing knowledge among employees within construction organisations. It comprised processes imitating management behaviour, consistency to culture, peer appreciation, mutuality, and honouring commitments. Previous BIM/IT research provides determinants of how social motivations promote the adoption decision by organisations. For instance, motivating individuals and groups for BIM adoption, and managing people resistance to BIM change (Mom et al., 2014); perceptions and attitudes towards the type of innovation (London and Singh, 2013; Waarts et al., 2002); managers apprehend social influence according to their perceptions instead of tangible understanding of the real world (Shim et al., 2009); positive/negative feelings and emotions towards IT use (Peansupap and Walker, 2005a); and product champion (Hameed et al., 2012).

5.4.3.6 Organisational culture

Organisational culture refers to the commonly shared norms, beliefs, principles, and traditions - held by members (i.e., employees) of an organisational practice or organisational unit – which helps to facilitate the members' understanding of the organisational functioning (Khazanchi et al., 2007; Robbins and Coulter, 2011). These shared values represent clear guides of the employees' intra-organisation behaviours and attitudes and their inter-organisation expected code of conduct (Tsai, 2011;

Deshpandé et al., 1993). Organisational culture is considered to act as a key factor affecting innovative IT/IS adoption and supply chain management practices (Stock et al., 2007; Khazanchi et al., 2007; Leidner and Kayworth, 2006; Yitmen, 2007). Leidner and Kayworth (2006) contend that firms are more likely to adopt an innovation (e.g., information system) if the standards and values included in the system conform to their organisational culture. Also, a firm applies caution by following its own particular principles and qualities instead of passively subjecting to the wide-spread traditions in its organisational domain (Greening and Gray, 1994). In this regard, a study by Liu et al. (2010a) investigated the mutual influence of the organisational culture and institutional pressures on firms' intention of innovation adoption considering how these effects moderated by the organisational culture. To explain the social acknowledgement of BIM (i.e., behavioural acceptance) from architects' point of view, organisations require to create a more conducive organisational culture and environment for BIM implementation. By doing this, organisations' target to enhance their staff and workers' perceptions of BIM usefulness will be achieved which, in turn, delivers successful BIM implementation (Son et al., 2015; Sebastian and van Berlo, 2010). The extant BIM/IT literature provides many determinants of how organisational culture affects the adoption decision by organisations. Enabling environment, and cultural change among industry stakeholders (Abubakar et al., 2014); openness, norm encouraging change, information sharing culture (Hameed et al., 2012); "organisational flexibility and adaptability to market, need for organisational restructuring, corporate management style (family owned or public owned), need for process reengineering for BIM, need to change in organisation characteristics for BIM (Mom et al., 2014); internal process perspective (Wu and Chen, 2014); supporting individual/ personal characteristics, open discussion environment, colleague help, and supervisor and organisational support (Peansupap and Walker, 2005a); and control orientation (Liu et al., 2010a)" (Ahmed and Kassem, 2018, p.121).

5.4.3.7 Willingness

Willingness is one of the critical factors towards affecting innovation (e.g., BIM /ICT) adoption (Xu et al., 2014; Son et al., 2015; Kim et al., 2015). It is critical for potential adopters (i.e., retailers) to comprehend what investments by providers demonstrate their dedication and willingness in putting resources into inter-organisational technologies. At the organisational level, the willingness of firms to adopt a new technology depends on these main factors: relative advantage and technological complexity (Tsai et al., 2013). In this respect, Son et al. (2015) delineate that support from top management, subjective norm, and compatibility are key factors influencing architects' behavioural willingness and intention to adopt BIM. Jih et al. (2007) argue that technology adoption willingness is impacted by the perception of risk-reduction measurements, perceived risks, and individual participation. Fox and Hietanen (2007) claim that the absence of well-skilled staff with both ICT and construction skills can obstruct the acquiring of BIM benefits. The absence of suitable training leads to losing the benefits of implementing innovative technologies. Hence, training is an essential factor affecting BIM implementation (Peansupap and Walker, 2005b). Consequently, it is believed that realising the value of BIM adoption may relatively rely on BIM technology proficient training, and when well-trained staff perceive that BIM is easy to use, they incline to show more willingness to implement BIM than untrained staff (Xu et al., 2014). In this regard, many research demonstrates that stakeholders' attitudes regarding BIM technologies are an essential factor in perceived ease of use (e.g., Kaner et al., 2008; Newton and Chileshe, 2012; Tookey, 2012). With regards to adopting a new technology/innovation, positive attitudes can improve individual' (and/or organisation) interests in learning BIM technologies and in this manner enhance the probabilities of a successful adoption. Premkumar and Potter (1995) pointed out that in spite of the fact that innovation may seem to be useful, the organisation may perceive it too complicated to use. Similarly, numerous studies have shown that individuals cannot or unwilling to adopt technologies since they feel vulnerable by the new complicated technology (Kaner et al., 2008; Tookey, 2012). Thus, potential adopters may be willing to adopt a new innovation if it is able to enhance the efficiency and easy to learn and easy to use, and they observe fewer risks and more benefits related to the new innovation adoption. Attitude affects interest in learning. At the point when individuals are not frightened of the complication of a technology (Gledson, 2016), this will bring about a more satisfied and viable BIM adoption (Xu et al., 2014). Therefore, the organisational behaviour willingness and intention to adopt an innovation is determined by perceived benefits (useful investment and risk-reduction) and perceived ease to use (ease of learning and training). The extant BIM/IT literature provides determinants of how behavioural willingness and intention affects the adoption decision by organisations: e.g., business interest (Gu and London, 2010); interest in learning BIM, and willingness to use BIM for stakeholders (Xu et al., 2014); need to innovate, innovativeness, and the diffusion of innovation (Singh and Holmstrom, 2015); incentives and enjoyment with innovation (Talukder, 2012); and competitive advantages in market (Gu and London, 2010; Mom et al., 2014; Peansupap and Walker, 2005a; Rogers et al., 2015; Takim et al., 2013).

5.4.3.8 Organisation size

Much has been written about the effective role of the organisation size in innovation adoption (Damanpour, 1996; Teo et al., 2003). However, in the organisational literature, a frequent controversy has been the part of organisation size in the innovation adoption process (Ettlie and Rubenstein, 1987; Forman, 2005). Many studies investigated the associations between firm/organisation size and innovation/new technology adoption, attempted to determine some of the controversial issues surrounding this matter (Shim et al., 2009). For instance, Ettlie and Rubenstein (1987) tested the linkages between the organisation size and the innovation through differentiating between the integration of radical and incremental technologies; Forman (2005) found disparities between simple and complicated ICT (i.e., internet technologies) when studied the impact of organisation size on technology adoption; and a study by Jung and Lee (2016) which considered the mediating role of the organisation size among three perceptual factors of organisational environment, management, and aspirations for organisational innovation. It resulted in various associations - according to organisation size – that determine the influence on the organisations' innovation adoption aspirations. The total number of full-time staff is the most usual measure of organisation size (Kimberly and Evanisko, 1981; Shim et al., 2009).

According to the Organisation size Management theory, there are some differences between small and large organisations (Shim et al., 2009). Small businesses must manage a lack of administration staff, individual recruitment burdens, financial confinements, and inadequate internal and external information. Whereas larger businesses can survive the obstacles in ICT development by the feature of their size, survival - for smaller firms - is the more instant concern (Liang et al., 2007). Thus, it is expected that organisation size offers a simple criterion for dividing organisations into groups demonstrating comparable ICT investment decisions: The larger organisation's size, the more likely it makes ICT investment decisions (Shim et al., 2009). Kimberly and Evanisko (1981, P. 699) argue that the growth in an organisation's size makes a "critical mass" that warrants employing certain innovations, larger firm size encourages staffs' aspiration for their adoption behaviour and organisational innovation. Also, since the increasing size frequently makes firms more distinguished as a method of justifying and organising their activities, specific managerial innovations are desirable as an outcome of the expansion in organisation size. Therefore, larger firms will most likely need innovation by virtue of their enlarged size and complexity. However, it is also essential to identify that expanding a firm's size is not necessarily promoting more noteworthy inventiveness (Damanpour, 1992; Hage, 1980); small firms have larger amounts of adaptability and capacity to adjust and progress. Hence, small firms can be more viable at adopting and implementing organisational innovation (Damanpour, 1992; Mintzberg, 1989).

5.5 Developing and testing the BIM Adoption Taxonomy measurement models

Due to the non-parametric (i.e., ordinal data) nature of the data of this study, Confirmatory Factor Analysis (CFA) was adopted as a statistical technique. "Confirmatory Factor Analysis was used to empirically evaluate and validate the measurement models that represent the taxonomy's constructs which are developed in the form of Structural Equation Modelling (SEM). Three individual CFA models were conducted due to the significant number of the observed items (i.e., 77 questionnaire items) compared to the number of acquired observations (i.e., 177 responses). This approach of testing a whole construct through its components or sub-dimensions is commonly used in previous studies (AL-Sabawy, 2013; Paiva et al., 2008). The models were tested by employing SPSS AMOS 24 and assessed by matching the following fit indices: Normed Chi-Square (χ^2/df) or (CMIN/DF), Root Mean Square Error of Approximation (RMSEA), P of Close Fit (PCLOSE), Root Mean-square Residual (RMR), and Comparative fit index (CFI) (Byrne, 2016; Hair et al., 2016). The criteria of the cut-off of these five fitness indices are listed in Table 5.1. Prior to assessing the First-order factor analysis of each driver (i.e., the *BIM innovation characteristics*; the *external environment characteristics*, and the *internal environment characteristics.*), One-factor congeneric measurement model of each construct (i.e., the 17 factors) was performed to measure the goodness-of-fit of these constructs. Furthermore, the three CFA measurement models were evaluated for validity and reliability" (Ahmed and Kassem, 2018, p.109).

Table 5.1 Cut-off of fitness indices

Index	Abbreviation	Acceptable level
Normed Chi-Square	χ^2/df or CMIN/DF	1-3
Root Mean Square Error of Approximation	RMSEA	≤0.08
P of Close Fit	PCLOSE	≥0.05
Root Mean-square Residual	RMR	<0.05
Comparative fit index	CFI	>.95

5.5.1 CFA models of the external environment characteristics driver (cluster)

The measurement models of this driver include three of One-factor congeneric measurement models for: "coercive pressures, mimetic pressures, and normative pressures" (Ahmed and Kassem, 2018, p.108); and one First-order factor analysis combining all these constructs into one measurement model (one cluster) as follows.

5.5.1.1 Coercive Pressures

Five items (i.e., XA_Q1, XA_Q2, XA_Q3, XA_Q4, and XA_Q5) were used to measure the coercive pressures construct. All the resulting indices for the **coercive pressures** construct were within the acceptable criteria according to cited indices: "CMIN/DF 0.951; CFI 1.000; RMR 0.0238; RMSEA 0.000; PCLOSE 0.669, and hence data shows a very good fit. Figure 5.3 depicts the One-factor congeneric measurement model of the coercive pressures construct" (Ahmed and Kassem, 2018, p.109).

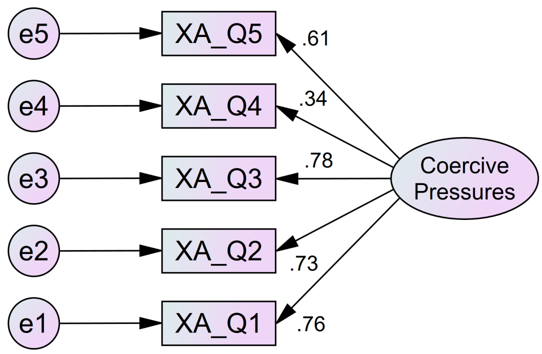


Figure 5.3 One-factor congeneric measurement model of Coercive Pressures construct

5.5.1.2 Mimetic pressures

This construct is measured by six items (i.e., XB_Q6, XB_Q7, XB_Q8, XB_Q9, XB_Q10, and XB_Q11). At the first iteration, "the model fit indices were: CMIN/DF 11.708; CFI 0.710; RMR 0.1334; RMSEA 0.247; PCLOSE 0.000" (Ahmed and Kassem, 2018, p.109). These results are considered under the acceptable threshold. Therefore, two iterations were conducted to eliminate the non-significant items in measuring the mimetic pressures construct, and to improve the indicators of model fit. The results of the first iteration indicate that item XB_Q10 '*Potential BIM adopters may imitate their main competitors' implementations*' has a high level of residual covariation with XB_Q11 '*Potential BIM adopters imitate the behaviour of other firms within their network*'. The value of residual covariation between those two factors was (67.829). The discrepancy between variables should be less than two in absolute for the Standardised Residual Covariances (Jöreskog et al., 2001). The absolute value (i.e., 2.58) of the standardised residual covariances should not be above 2.58 or below - 2.58 (Byrne, 2016; Pedhazur and Schmelkin, 2013), and the Modification Indices (MI) that show high covariance between residuals accompanied by high regression weights between these residuals' construct are candidates for deletion (Byrne, 2016; Hair et al., 2016). Despite the elimination of XB_Q10, there is still high covariance between XB_Q11, which has the highest regression weight, with the other items, therefore, the decision was made to eliminate XB_Q11 too. After the deletion of those items, the results at the final iteration were: "CMIN/DF 0.888; CFI 1.000; RMR 0.0180; RMSEA 0.000; PCLOSE 0.554" (Ahmed and Kassem, 2018, p.109). These results show that the model fit indices have been improved and with excellent fit. Figure 5.4 shows the mimetic pressures construct measurement model at the first and final iterations.

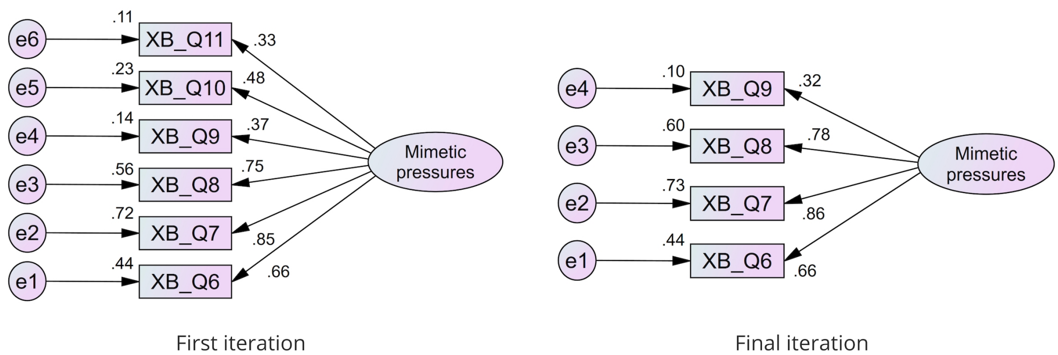


Figure 5.4 One-factor congeneric measurement models of Mimetic Pressures construct at the first and final iterations

5.5.1.3 Normative pressures

Five items (i.e., XC_Q12, XC_Q13, XC_Q14, XC_Q15, and XC_Q16) were employed to measure the one-factor congeneric measurement model of the normative pressures construct. At the first iteration, the model fit indices were: "CMIN/DF 2.897; CFI

0.899; RMR 0.1334; RMSEA 0.104; PCLOSE 0.066" (Ahmed and Kassem, 2018, p.109). These results indicated that the model does not fit and the problem in this construct was identified that is the modification indices showed a high cross loading between item XC_Q12 '*BIM has already been widely adopted by our clients*' and item XC_Q14 '*The BIM norms, standards, and policies motivated and helped our organisation to adopt BIM*'. Thus, in order to solve this issue, covering error variance terms of those two items was applied. "The results at the final iteration were: CMIN/DF 1.263; CFI 0.989; RMR 0.0283; RMSEA 0.039; PCLOSE 0.488. Based on the results, the model has been significantly improved with a very good fit" (Ahmed and Kassem, 2018, p.109). Figure 5.5 shows the normative pressures construct measurement model at the first and final iterations.

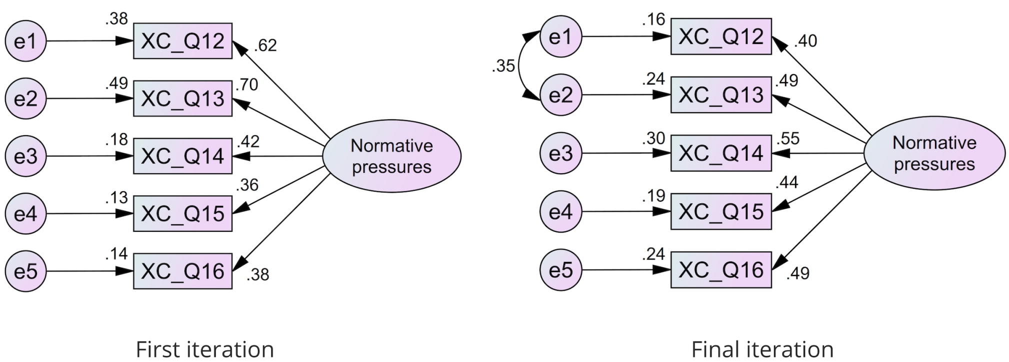


Figure 5.5 One-factor congeneric measurement models of Normative Pressures construct at the first and final iterations

5.5.1.4 External environment characteristics measurement model

"The external environment characteristics driver comprised fourteen items and represented by three sub-dimensions (i.e., constructs): coercive pressures, mimetic pressures, and normative pressures. First-order factor analysis was applied to this driver/construct. All the resulting indices were within the acceptable criteria according to cited indices: CMIN/DF 1.979; CFI 0.931; RMR 0.0632; RMSEA 0.075; PCLOSE 0.014, and hence, data shows a very good fit. Figure 5.6 depicts the CFA measurement model of the external environment characteristics construct (cluster)" (Ahmed and Kassem, 2018, p.109).

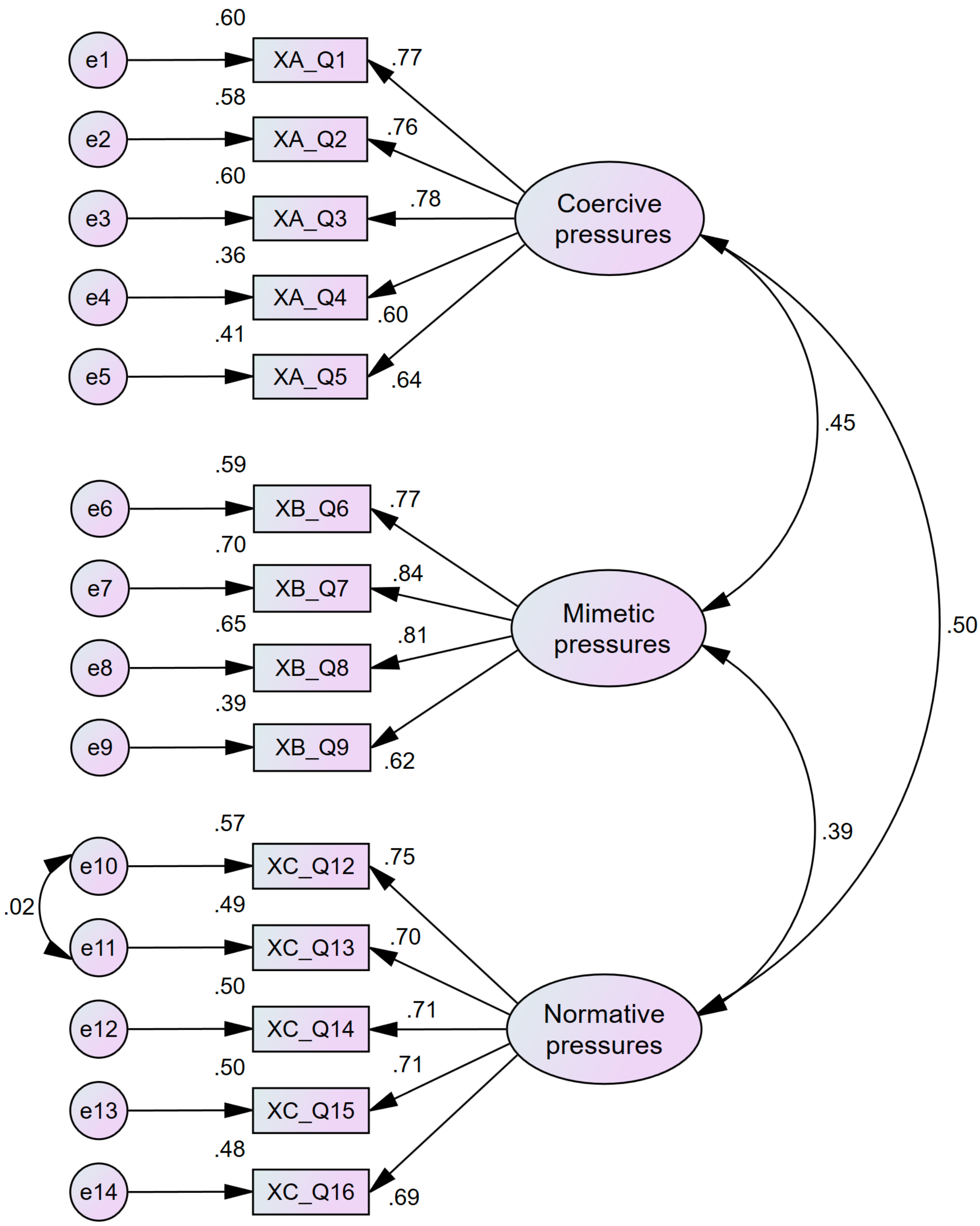


Figure 5.6 CFA measurement model of the External Environment Characteristics construct

5.5.2 CFA models of the BIM innovation characteristics driver (cluster)

The measurement models of this driver include six of One-factor congeneric measurement models for: "relative advantage, compatibility, complexity, trialability, observability, and technological factors" (Ahmed and Kassem, 2018, p.113); and one First-order factor analysis combining all these constructs into one measurement model (one cluster) as follows.

5.5.2.1 Relative advantage

In respect of relative advantage, six items (i.e., YA_Q17, YA_Q18, YA_Q19, YA_Q20, YA_Q21, and YA_Q22) were input to measure the one-factor congeneric measurement model of this construct. "[At the first iteration, the model fit indices were: CMIN/DF 3.895; CFI 0.915; RMR 0.0600; RMSEA 0.128; PCLOSE 0.002. These results indicated that the model does not fit as item YA_Q19 '*Adopting BIM is perceived to shorten the duration of a construction project*' has a high level of residual covariation with item YA_Q18 '*Adopting BIM is perceived to reduce overall cost*']" (Ahmed and Kassem, 2018, p.113). The value of residual covariation between those two factors was (12.086). Thus, to improve the indicators of model fit, the decision was made to eliminate item YA_Q19. After the deletion of this item, "the results at the final iteration were: CMIN/DF 1.640; CFI 0.987; RMR 0.0319; RMSEA 0.060; PCLOSE 0.341" (Ahmed and Kassem, 2018, p.113). These results show that the model fit indices have been improved and with excellent fit. Figure 5.7 shows the relative advantage construct measurement model at the first and final iterations

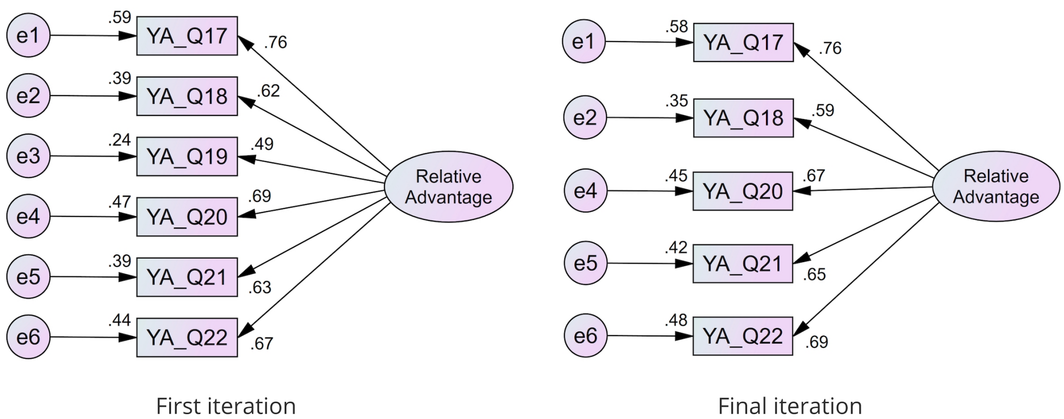


Figure 5.7 One-factor congeneric measurement models of relative advantage construct at the first and final iterations

5.5.2.2 Compatibility

This construct includes only two items (i.e., YB_Q23 and YB_Q24). Since the number of items per factor is critical (Raubenheimer, 2004), especially when a scale to measure only one factor, it is required three items at minimum that must load significantly on each factor in a multidimensional scale to be properly identified (Costello and Osborne, 2005; Raubenheimer, 2004; Yong and Pearce, 2013). As noted by Kline (2015, p.172), "models with factors that have only two indicators are more prone to estimation problems, especially when the sample size is small". Therefore, the CFA of this construct will not be valid since the minimum to undertake the One-factor congeneric measurement is three items per factor. Hence, this construct will be measured together with its pertinent group of factors (Factors underlying the innovation characteristics driver) within a multidimensional scale (Raubenheimer, 2004).

5.5.2.3 Complexity

Four items (i.e., YC_Q25, YC_Q26, YC_Q27, and YC_Q28) were used to measure the complexity construct. All the resulting indices were within the acceptable criteria according to cited indices: "CMIN/DF 0.562; CFI 1.000; RMR 0.0215; RMSEA 0.000; PCLOSE 0.691, and hence data shows a very good fit. Figure 5.8 depicts the One-factor congeneric measurement model of the complexity construct" (Ahmed and Kassem, 2018, p.113).

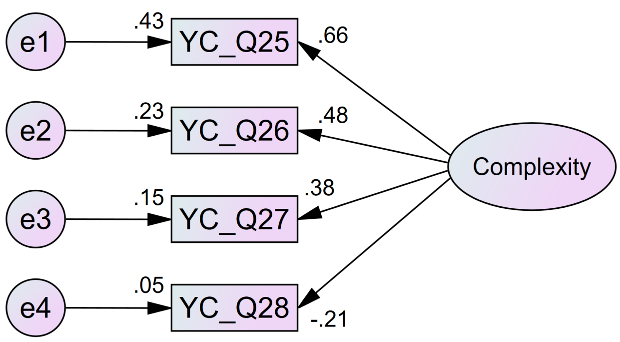


Figure 5.8 One-factor congeneric measurement model of Complexity construct

5.5.2.4 Trialability

This construct includes only two items (i.e., YD_Q29 and YD_Q30), therefore, the CFA of this construct will not be valid since the minimum to undertake the One-factor congeneric measurement is three items. Hence, this construct will be measured together with its pertinent group of factors (Factors underlying the innovation characteristics driver) within a multidimensional scale.

5.5.2.5 Observability

Three items (i.e., YE_Q31, YE_Q32, and YE_Q33) were employed to measure the observability construct. All the resulting indices were within the acceptable criteria according to cited indices: "CMIN/DF 1.048; CFI 1.000; RMR 0.0148; RMSEA 0.017; PCLOSE 0.405, and hence data shows a very good fit. Figure 5.9 depicts the One-factor congeneric measurement model of the Observability construct" (Ahmed and Kassem, 2018, p.113).

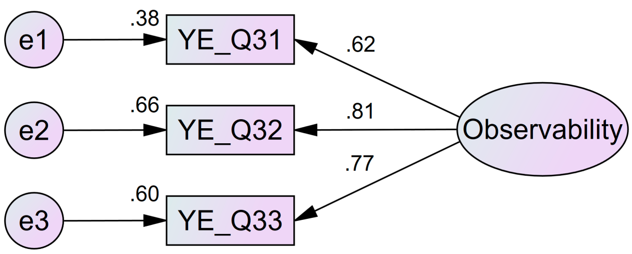


Figure 5.9 One-factor congeneric measurement model of Observability construct

5.5.2.6 Technological factors

In respect of Technological factors, four items (i.e., YF_Q34, YF_Q35, YF_Q36, and YF_Q37) were input to measure the "one-factor congeneric measurement model of this construct. All the resulting indices were within the acceptable criteria according to cited indices: CMIN/DF 0.028; CFI 1.000; RMR 0.0040; RMSEA 0.000; PCLOSE 0.982, and hence data shows a very good fit. Figure 5.10 depicts the One-factor congeneric measurement model of the Technological factors construct" (Ahmed and Kassem, 2018, p.113).

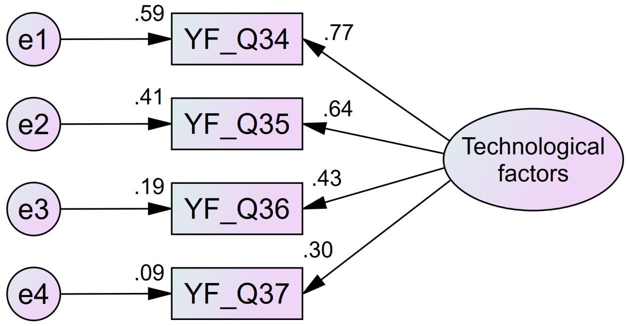


Figure 5.10 One-factor congeneric measurement model of Technological Factors construct

5.5.2.7 Innovation characteristics measurement model

The innovation characteristics driver encompassed twenty items and represented by six sub-dimensions (i.e., constructs): "relative advantage, compatibility, complexity, trialability, observability, and technological factors. First-order factor analysis was conducted on this driver/construct. All the resulting indices were within the acceptable criteria according to cited indices: CMIN/DF 1.578; CFI 0.929; RMR 0.0601; RMSEA 0.068; PCLOSE 0.185, and hence, data shows a very good fit. Figure 5.11 depicts the CFA measurement model of the innovation characteristics construct (cluster)" (Ahmed and Kassem, 2018, p.124).

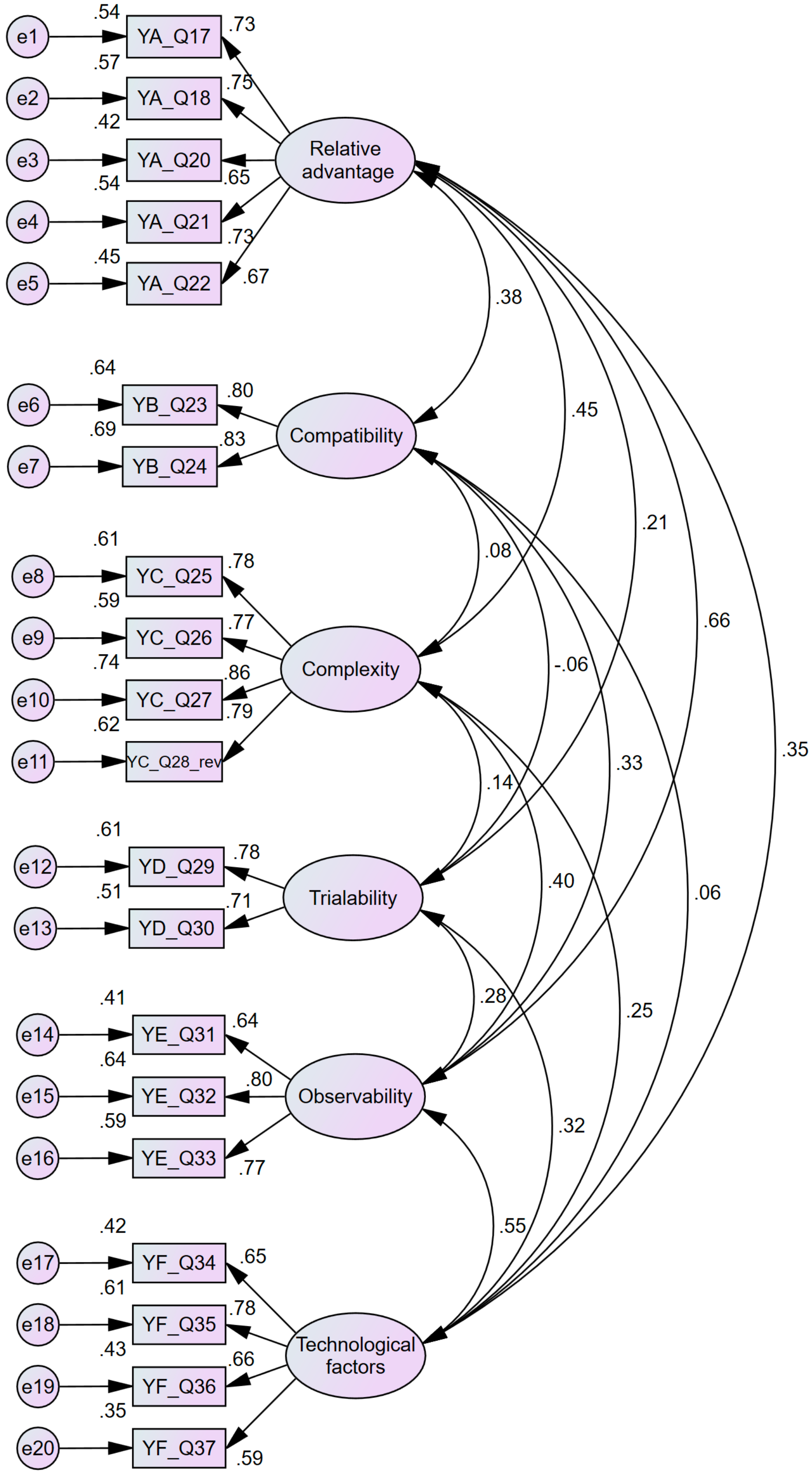


Figure 5.11 CFA measurement model of the Innovation Characteristics construct

5.5.3 CFA models of the internal environment characteristics driver (cluster)

The measurement models of this driver include eight of One-factor congeneric measurement models for: "top management support, communication behaviour, financial resources, organisational readiness, social motivations, organisational culture, Willingness, and organisation size" (Ahmed and Kassem, 2018, p.124); and one First-order factor analysis combining all these constructs into one measurement model (one cluster) as follows.

5.5.3.1 Top management support

Three items (i.e., ZA_Q38, ZA_Q39, and ZA_Q40) were used to measure the top management support construct. All the resulting indices were within the acceptable criteria according to cited indices: CMIN/DF 0.920; CFI 1.000; RMR 0.0075; RMSEA 0.000; PCLOSE 0.436, and hence data shows a very good fit. Figure 5.12 depicts the One-factor congeneric measurement model of the Top management support construct.

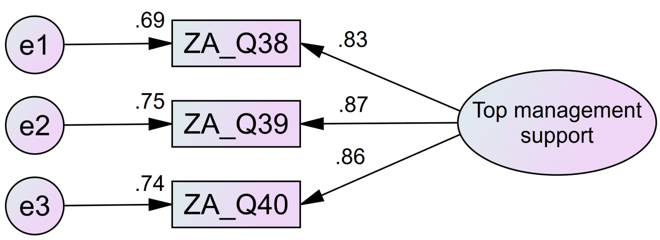


Figure 5.12 One-factor congeneric measurement model of Top Management Support construct

5.5.3.2 Communication behaviour

This construct is measured by five items (i.e., ZB_Q41, ZB_Q42, ZB_Q43, ZB_Q44 and ZB_Q45). At the first iteration, "the model fit indices were: CMIN/DF 9.758; CFI 0.819; RMR 0.0937; RMSEA 0.223; PCLOSE 0.000" (Ahmed and Kassem, 2018, p.124). These results indicated that the model does not fit as item ZB_Q45 '*Interpersonal channels helped our organisation to understand more about BIM*' has a high level of residual covariation with item ZB_Q44 '*The internet/social media helped our organisation to understand more about BIM*'. The value of residual covariation between those two factors was (24.913). Thus, to improve the indicators of model fit, the decision was made to eliminate item ZB_Q45. After the deletion of this item, "the results at the final iteration were: CMIN/DF 0.495; CFI 1.000; RMR 0.0165; RMSEA 0.000; PCLOSE 0.723" (Ahmed and Kassem, 2018, p.124). These results show that the model fit indices have been improved and with excellent fit. Figure 5.13 shows the communication behaviour construct measurement model at the first and final iterations.

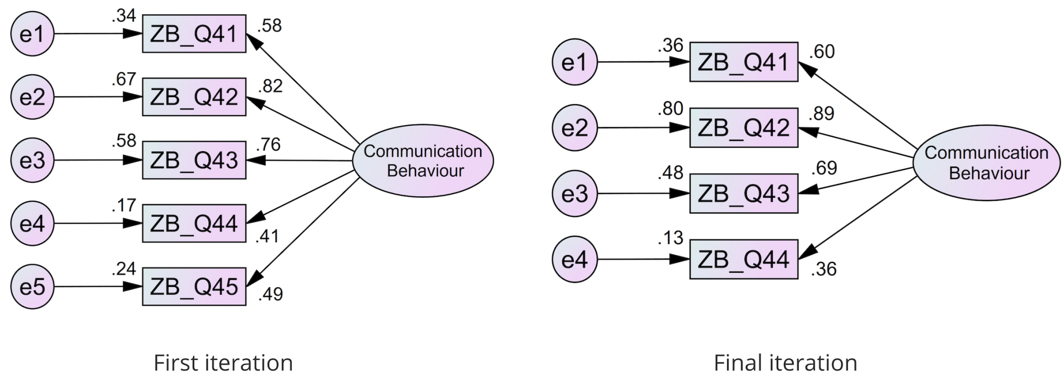


Figure 5.13 One-factor congeneric measurement models of Communication Behaviour construct at the first and final iterations

5.5.3.3 Financial resources

Four items (i.e., ZC_Q46, ZC_Q47, ZC_Q48, and ZC_Q49) were employed to measure the one-factor congeneric measurement model of the financial resources construct. At the first iteration, "the model fit indices were: CMIN/DF 16.349; CFI 0.808; RMR 0.1083; RMSEA 0.295; PCLOSE 0.000" (Ahmed and Kassem, 2018, p.124). These results indicated that the model does not fit as item ZC_Q46 '*Our organisation has allocated a yearly budget for IT technologies that facilitated the decision to adopt BIM*' has a high level of residual covariation with item ZC_Q47 '*The required cost to secure BIM was a key element in the decision to adopt*'. The value of residual covariation between those two factors was (24.269). Thus, to improve the indicators of model fit, the decision was made to eliminate item ZC_Q46. After the deletion of this item, "the results at the final iteration were: CMIN/DF 1.432; CFI 0.996; RMR 0.0205; RMSEA 0.050; PCLOSE 0.328" (Ahmed and Kassem, 2018, p.124). These results show that the model fit indices have been improved and with excellent fit. Figure 5.14 shows the financial resources construct measurement model at the first and final iterations.

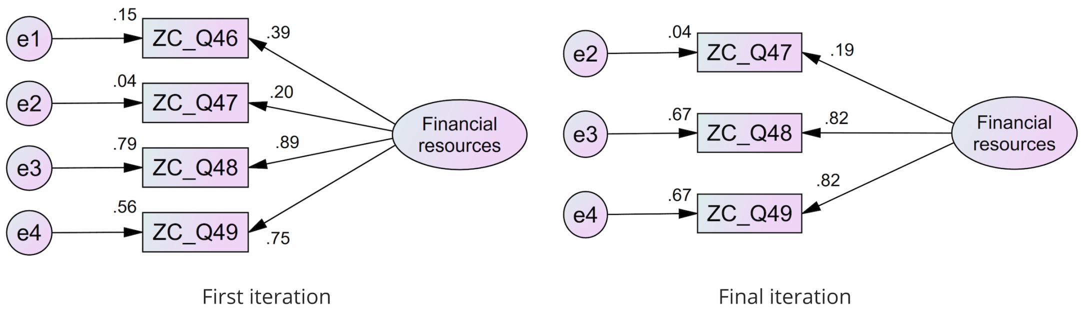


Figure 5.14 One-factor congeneric measurement models of Financial Resources construct at the first and final iterations

5.5.3.4 Organisational readiness

Eleven items (i.e., ZD_Q50, ZD_Q51, ZD_Q52, ZD_Q53, ZD_Q54, ZD_Q55, ZD_Q56, ZD_Q57, ZD_Q58, ZD_Q59, and ZD_Q60) were input to measure the "[one-factor congeneric measurement model of the organisational readiness construct. Seven iterations were performed to reach the fit model. At the first iteration, the model fit indices were: CMIN/DF 4.558; CFI 0.677; RMR 0.1128; RMSEA 0.142; PCLOSE 0.000. These results indicated that the model does not fit. The highest value of residual covariation was between items ZD_Q58 and ZD_Q59 (i.e., 40.451). Item ZD_Q58 is '*BIM adoption requires the availability and effectiveness of human capability/resource for keeping the best people*']" (Ahmed and Kassem, 2018, p.124). Item ZD_Q59 is '*BIM adoption requires intra-organisational management support*'. The second highest residual covariation was between items ZD_Q56 and ZD_Q57. The value of residual covariation was (16.014). Item ZD_Q56 is '*The technical competence of staff should be considered before taking the decision to adopt BIM*'. Item

ZD_Q57 is '*Research and development capability of an organisation is required to adopt BIM*'. The last highest residual covariation was between items ZD_Q59 and ZD_Q60 (i.e., 14.600). Item ZD_Q60 is '*BIM adoption requires prior experience and IT expertise*'. During the first six iterations, the decision has been to eliminate ZD_Q59, ZD_Q58, ZD_Q57, ZD_Q56, and ZD_Q60 respectively to improve the model fit as the Standardised Regression Weights and the Squared Multiple Correlations of these items were very close. However, the indicators show that the model improved but still does not fit. "[The issue was identified that the modification indices showed a high cross loading between item ZD_Q52 '*Our organisation has provided a professional BIM technology training*' and item ZD_Q54 '*Our organisation has employed experienced staff to adopt BIM*'. Thus, in order to solve this issue, covering error variance terms of those two items was applied. The results at the final iteration were: CMIN/DF 1.761; CFI 0.980; RMR 0.0360; RMSEA 0.066; PCLOSE 0.279]" (Ahmed and Kassem, 2018, p.124). Based on the results, the model has been significantly improved with a very good fit. Figure 5.15 shows the organisational readiness construct measurement model at the first and final iterations.

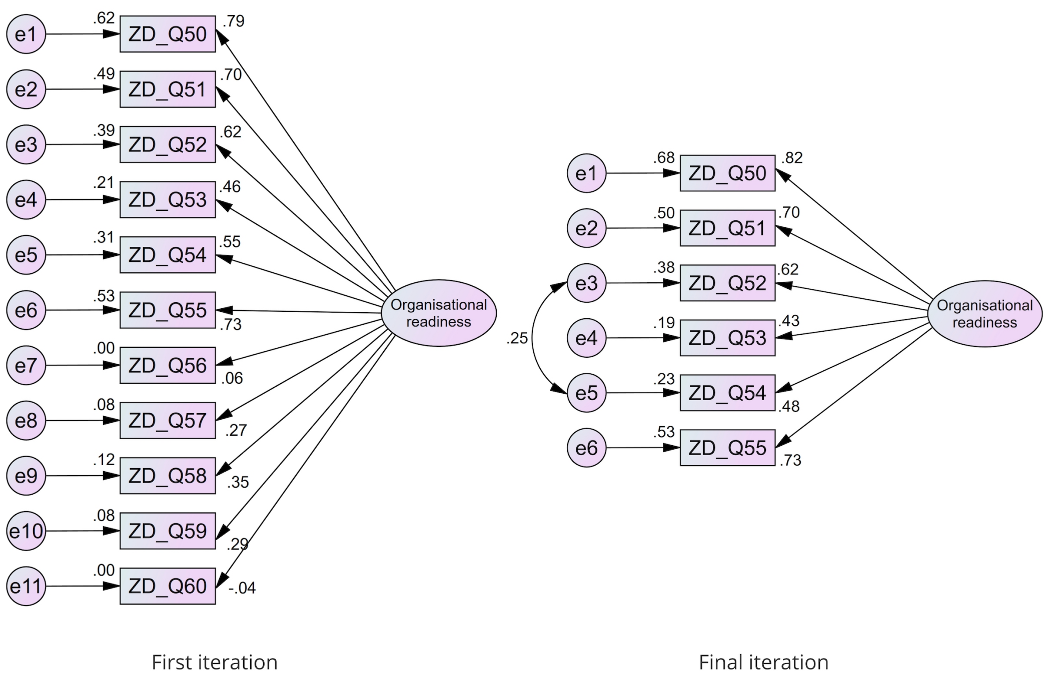


Figure 5.15 One-factor congeneric measurement models of Organisational Readiness construct at the first and final iterations

5.5.3.5 Social motivations

This construct is measured by five items (i.e., ZE_Q61, ZE_Q62, ZE_Q63, ZE_Q64 and ZE_Q65). At the first iteration, "the model fit indices were: CMIN/DF 3.382; CFI 0.902; RMR 0.0569; RMSEA 0.116; PCLOSE 0.032" (Ahmed and Kassem, 2018, p.124). These results indicated that the model does not fit as item ZE_Q62 '*It was necessary to manage people who were resistant to change towards BIM*' has a high level of residual covariation with item ZE_Q65 '*It is necessary to maintain the championing image motives of a good using of advance technologies to facilitate the BIM adoption*'. The value of residual covariation between those two factors was (4.490). Thus, to improve the indicators of model fit, the decision was made to eliminate item ZE_Q62. After the deletion of this item, "the results at the final iteration were: CMIN/DF 1.510; CFI 0.989; RMR 0.0283; RMSEA 0.054; PCLOSE 0.359" (Ahmed and Kassem, 2018, p.124). These results show that the model fit indices have been improved and with excellent fit. Figure 5.16 shows the social motivations construct measurement model at the first and final iterations.

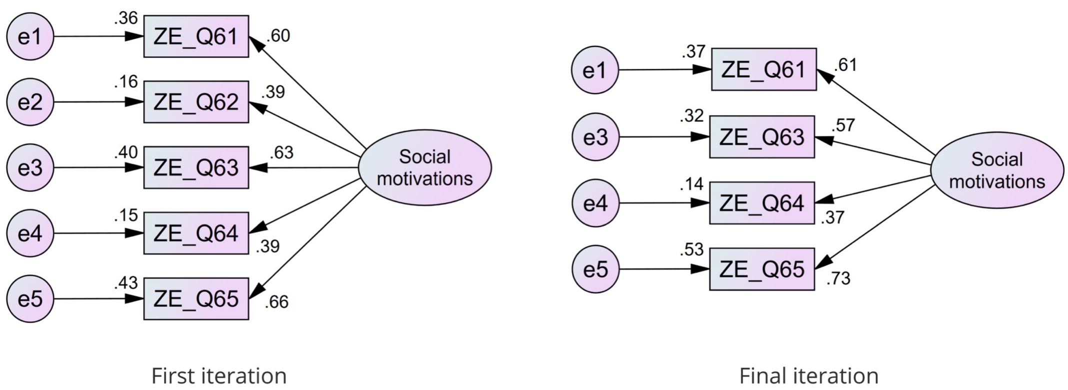


Figure 5.16 One-factor congeneric measurement models of Social Motivations construct at the first and final iterations

5.5.3.6 Organisational culture

Three items (i.e., ZF_Q66, ZF_Q67, ZF_Q68, ZF_Q69, and ZF_Q70) were used to measure the top management support construct. All the resulting indices were within the acceptable criteria according to cited indices: "CMIN/DF 1.719; CFI 0.981; RMR 0.0374; RMSEA 0.064; PCLOSE 0.311, and hence data shows a very good fit. Figure 5.17 depicts the One-factor congeneric measurement model of the organisational culture construct" (Ahmed and Kassem, 2018, p.124).

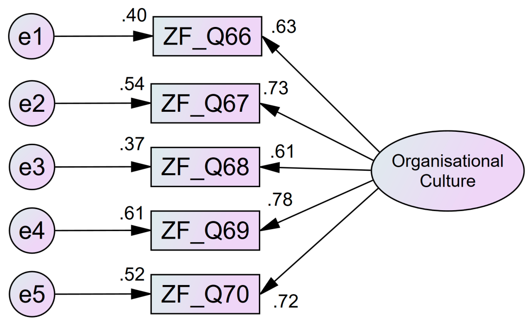


Figure 5.17 One-factor congeneric measurement model of Organisational Culture construct

5.5.3.7 Willingness

This construct is measured by five items (i.e., ZG_Q71, ZG_Q72, ZG_Q73, ZG_Q74, and ZG_Q75). At the first iteration, "the model fit indices were: CMIN/DF 3.495; CFI 0.916; RMR 0.0534; RMSEA 0.119; PCLOSE 0.027" (Ahmed and Kassem, 2018, p.124). These results indicated that the model does not fit as item ZG_Q73 '*Our organisation has the need to innovate*' has a high level of residual covariation with item ZG_Q71 '*BIM adoption helps to achieve competitive advantages in the market*'. The value of residual covariation between those two factors was (4.904). Thus, to improve the indicators of model fit, the decision was made to eliminate item ZG_Q73. After the deletion of this item, "the results at the final iteration were: CMIN/DF 0.854; CFI 1.000; RMR 0.0223; RMSEA 0.000; PCLOSE 0.567" (Ahmed and Kassem, 2018, p.124). These results show that the model fit indices have been improved and with excellent fit. Figure 5.18 shows the Willingness construct measurement model at the first and final iterations.

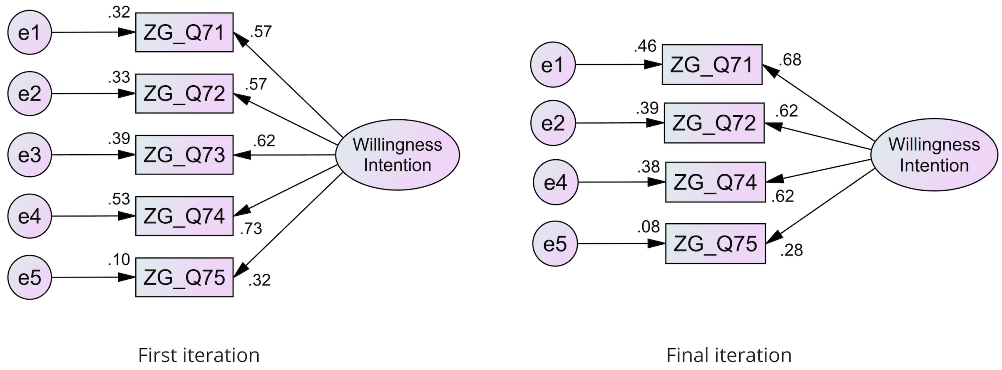


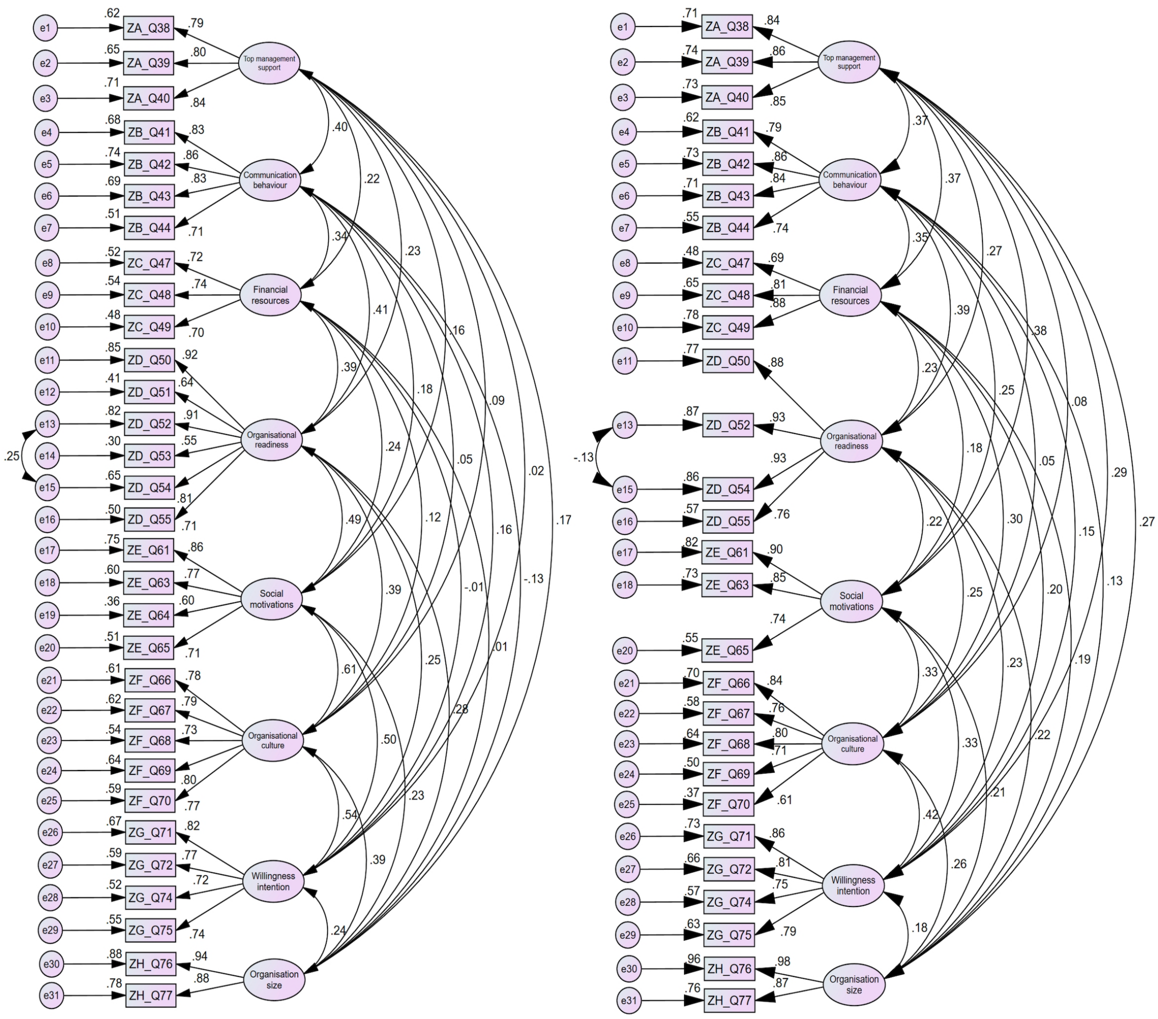
Figure 5.18 One-factor congeneric measurement model of Willingness construct at the first and final iterations

5.5.3.8 Organisation size

This construct includes only two items (i.e., ZH_Q76 and ZH_Q77), therefore, the CFA of this construct will not be valid since the minimum to undertake the One-factor congeneric measurement is three items. Hence, this construct will be measured together with its pertinent group of factors (Factors underlying the Internal environment characteristics) within a multidimensional scale.

5.5.3.9 Internal environment characteristics measurement model

" The internal environment characteristics driver encompassed thirty-one items and represented by eight sub-dimensions: top management support, communication behaviour, financial resources, organisational readiness, social motivations, organisational culture, Willingness, and organisation size" (Ahmed and Kassem, 2018, p.108). First-order factor analysis was conducted on this driver/construct. Four iterations were performed to reach the fit model. At the first iteration, the model fit indices were: "[CMIN/DF 1.387; CFI 0.474; RMR 0.1055; RMSEA 0.047; PCLOSE 0.753. These results indicated that the model does not fit. The highest value of residual covariation was between items ZD_Q51 and ZD_Q52 (i.e., 6.735). Item ZD_Q51 is '*Our ability to adapt the technologies enabled us to adopt BIM*'. Item ZD_Q52 is '*Our organisation has provided a professional BIM technology training*'. The second highest residual covariation was between items ZD_Q53 and ZE_Q61. The value of residual covariation was (6.051). Items ZD_Q53 is '*Technological capability of an organisation is key to the decision to adopt BIM*'. Item ZE_Q61 is '*It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption*']" (Ahmed and Kassem, 2018, p.108). During the second and third iterations, the decision has been to eliminate ZD_Q51 and ZD_Q53 respectively to improve the model fit as the Standardised Regression Weights and the Squared Multiple Correlations of these items were very close. However, the indicators show that the model improved but still does not fit. The issue was identified that the modification indices showed a high residual covariation between items ZE_Q64 and ZC_Q47 (i.e., 4.068) with very close Standardised Regression Weights between item ZE_Q64 and item ZC_Q48 (i.e., 4.737), and item ZC_Q47 (i.e., 4.134) respectively. "Item ZE_Q64 is '*Social pressures are captured based on managers' perceptions rather than an actual understanding of the real world*'; item ZC_Q47 is '*The required cost to secure BIM was a key element in the decision to adopt*'; and item ZC_Q48 is '*Our organisation perceived BIM as an affordable innovation*'. Thus, in order to solve this issue, the decision has been to also eliminate ZE_Q64. The results at the final iteration were: CMIN/DF 1.177; CFI 0.980; RMR 0.0460; RMSEA 0.032; PCLOSE 0.995. Based on the results, the model has been significantly improved with a very good fit. Figure 5.19 shows the CFA measurement models of the internal environment characteristics construct (cluster) at the first and final iterations" (Ahmed and Kassem, 2018, p.108).



First iteration

Final iteration

Figure 5.19 CFA measurement models of the Internal Environment construct

5.6 Testing validity and reliability of the proposed taxonomy

"Measurement validity and reliability is considered to be a crucial stage in social research. Shortcomings in the validity and reliability of the measurement may cause adverse effects on the quality of data. The results of testing the three CFA measurement models of the investigated drivers (i.e., External environment characteristics, innovation characteristics, and internal environment characteristics) are used as the input to evaluate the validity and reliability of these proposed models" (Ahmed and Kassem, 2018, p.109). Table 5.2, Table 5.3, Table 5.4, and Table 5.5 shows the results of performing the CFA in testing the measurement models.

5.6.1 Validity

Measurement validity was assessed by applying various statistical indicators: convergent validity, construct validity, and discriminant validity, which are described in the following sections.

5.6.1.1 Convergent validity

According to the convergent validity, it is required "that the factor loading of each item in the construct should be statistically significant from zero and the validity will be achieved when the value of the factor loading exceeds 0.50 (Hair et al., 2016)" (Ahmed and Kassem, 2018, p.109). The resulting values of the factor loading for the majority items used in this study were more than 0.70 which confirming the validity of the constructs. The factor loading values for the *external environment characteristics* driver items were between 0.598 and 0.835 (Table 5.2). The factor loading values for the *innovation characteristics* driver items were between 0.611 and 0.852 (Table 5.3). The factor loading values for the *internal environment characteristics* driver items were between 0.611 and 0.981 (Table 5.4). Furthermore, these results indicate that all the regressions are significant since the critical ratio of the indicators were more than 1.96.

5.6.1.2 Construct validity

Regarding testing the construct validity, the "goodness-of-fit of the indices pertain to their constructs were employed. The three main drivers/constructs (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics) and their sub-dimensions have achieved a good fit and their indices show evidence of the validity of these constructs. Table 5.5 summarises the results of conducting first-order factor analysis (i.e., CFA measurement models)" (Ahmed and Kassem, 2018, p.109).

5.6.1.3 Discriminant validity

Concerning discriminant validity, it relies on the rule of thumb method in which the "square root of average variance extracted of each construct should exceed its correlation with other constructs (Chin, 1998; Guo et al., 2011). By conducting this method, the results of the sub-dimensions (i.e., constructs) of the three main drivers/constructs (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics) have shown a satisfactory level of discriminant validity. Table 5.6, Table 5.7, and Table 5.8 show the inter-correlation matrices of discriminant validity for the external environment characteristics, innovation characteristics, and internal environment characteristics" (Ahmed and Kassem, 2018, p.109).

5.6.2 Reliability

In the current study, four indicators (i.e., tests) are employed to assess the reliability of the models: "Squared Multiple Correlation (SMC) 'item reliability'; Cronbach's alpha; Construct Reliability (composite reliability) (CR); and Average variance extracted (AVE)" (Ahmed and Kassem, 2018, p.109). These indicators are described in the following sections.

5.6.2.1 Squared Multiple Correlation

Squared Multiple Correlation (SMC) is considered to represent the key indicator in measuring the reliability of the observed variables (Schumacker, 2004) of each item (Bagozzi and Yi, 2012). The minimum acceptable SMC value is > 0.30 (Holmes-Smith, 2011). The observed item which its SMC value exceeds > 0.50, it has good reliability. Seven items, of the *external environment characteristics* driver, out of 14 exceeded 0.50, which represent 50% of the total items. One item (i.e., XC_Q14) equal to 0.50. Four items were between 0.406 and 0.499. Two items were less than 0.40: XA_Q4 (0.357) and XB_Q9 (0.385). In respect of the *innovation characteristics* driver, 13 items out of 20 were exceeded 0.50, which represent 65% of the total items. Three items were between 0.410 and 0.472. Four items were above 0.30. Concerning the *internal environment characteristics* driver, 26 items out of 28 were exceeded 0.50, which represent 93% of the total items. One item (i.e., ZC_Q47) was above 0.40 (0.478), and one item (i.e., ZF_Q70) was above 0.30 (0.374). Therefore, based on the resulting SMC values, all the given items that used to measure the constructs of the three models are reliable (Table 5.2, Table 5.3, and Table 5.4).

5.6.2.2 Cronbach's alpha

Regarding Cronbach's alpha, which is basically "used to test the reliability of the internal consistency, the cut-off value of this indicator is 0.70 (Hair et al., 2016; Nunnally and Bernstein, 1994). All sub-dimensions (i.e., constructs) of three main drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics)" (Ahmed and Kassem, 2018, p.109) have exceeded the acceptable value within the range between 0.768 and 0.921 and achieved a very satisfying reliability indicator of the models (Table 5.2, Table 5.3, and Table 5.4).

5.6.2.3 Construct Reliability

The Construct Reliability (CR) indicator is based on "the measuring the level of Coefficient H, which is suggested by Hancock and Mueller (2001) also to test the reliability of the internal consistency. The acceptable level of Coefficient H is 0.70. All the resulting CR values of the constructs of three main drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics)" (Ahmed and Kassem, 2018, p.109) have exceeded 0.70 within the range between 0.723 and 0.929 that indicate a high level of reliability of the constructs (Table 5.2, Table 5.3, and Table 5.4).

5.6.2.4 Average variance extracted

"Average Variance Extracted (AVE) was also applied to assess the reliability of constructs. All the results of the constructs of three main drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics) and their sub-dimensions, except 'Technological factors', have exceeded the acceptable level of 0.50. However, since the Average Variance Extracted value for 'Technological factors' was 0.454, which is very close to the acceptable level of 0.50, and the other reliability indicators (i.e., Cronbach's alpha, Coefficient H, and construct reliability) were higher than the acceptable levels, the reliability of the 'Technological factors' construct was supported" (Ahmed and Kassem, 2018, p.109) (Table 5.2, Table 5.3, and Table 5.4).

Finally, at this stage, the analysis of the sample data enabled the "testing of the validity and reliability of measurements implemented in the current study. Three tests were employed to evaluate the validity: convergent validity, construct validity, and discriminant validity. All the results of applying these types of test confirm that the measurement is significantly valid to evaluate the constructs of the BIM adoption drivers. Furthermore, four tests were used to assess the reliability: Squared Multiple Correlation (SMC) 'item reliability'; Cronbach's alpha; Construct Reliability (CR)/ (composite reliability); and Average variance extracted (AVE). All the results of these tests indicate the reliability of instrument used in, and the collected data for this study is highly reliable that will be leading to valid results which can be generalised under varied positions. Therefore, it can be concluded that the validation of the proposed BIM adoption taxonomy was achieved" (Ahmed and Kassem, 2018, p.109).

Table 5.2 Results of the CFA measurement model of the external environment characteristics

Construct	Item retained	Factor loading	p-value	S.M.C (R^2)	Composite reliability (C.R.)		AVE	Cronbach's Alpha
Coercive pressures	XA_Q1	.771	***	.595	8.112	.836	.508	.836
	XA_Q2	.762	***	.580	8.044			
	XA_Q3	.776	***	.602	8.142			
	XA_Q4	.598	***	.357	6.680			
	XA_Q5	.637		.406				
Mimetic pressures	XB_Q6	.771	***	.594	7.973	.846	.582	.843
	XB_Q7	.835	***	.697	8.346			
	XB_Q8	.806	***	.649	8.193			
	XB_Q9	.621		.385				
Normative pressures	XC_Q12	.754	***	.569	8.314	.837	.508	.839
	XC_Q13	.701	***	.491	7.779			
	XC_Q14	.707	***	.500	8.132			
	XC_Q15	.706	***	.499	8.121			
	XC_Q16	.693		.481				

**** = 0.001; S.M.C: Squared Multiple Correlation; AVE: Average variance extracted*

Table 5.3 Results of the CFA measurement model of the innovation characteristics

Construct	Item retained	Factor loading	p-value	S.M.C (R^2)	Composite reliability (C.R.)		AVE	Cronbach's Alpha
Relative advantage	YA_Q17	.687	***	.472	7.189	.831	.500	.806
	YA_Q18	.812	***	.659	7.984			
	YA_Q20	.611	***	.373	6.592			
	YA_Q21	.786	***	.618	7.853			
	YA_Q22	.614		.377				
Compatibility	YB_Q23	.803	***	.645	4.706	.798	.664	.798
	YB_Q24	.826		.683				
Complexity	YC_Q25	.776	***	.602	10.677	.877	.641	.877
	YC_Q26	.779	***	.606	10.726			
	YC_Q27	.852	***	.726	11.772			
	YC_Q28	.793		.629				
Trialability	YD_Q29	.792	***	.627	13.036	.723	.566	.717
	YD_Q30	.711	***	.505	13.036			
Observability	YE_Q31	.629	***	.396	7.402	.781	.546	.774
	YE_Q32	.819	***	.671	8.400			
	YE_Q33	.756		.571				
Technological factors	YF_Q34	.633	***	.410	6.348	.768	.454	.768
	YF_Q35	.744	***	.554	6.911			
	YF_Q36	.684	***	.468	6.662			
	YF_Q37	.629		.396				

**** = 0.001; S.M.C: Squared Multiple Correlation; AVE: Average variance extracted*

Table 5.4 Results of the CFA measurement model of the internal environment characteristics

Construct	Item retained	Factor loading	p-value	S.M.C (R^2)	Composite reliability (C.R.)		AVE	Cronbach's Alpha
Top management support	ZA_Q38	.840	***	.705	13.103	.888	.725	.890
	ZA_Q39	.861	***	.741	13.460			
	ZA_Q40	.854		.730				
Communication behaviour	ZB_Q41	.786	***	.618	10.178	.882	.652	.880
	ZB_Q42	.856	***	.732	11.046			
	ZB_Q43	.842	***	.709	10.888			
	ZB_Q44	.741		.549				
Financial resources	ZC_Q47	.691	***	.478	9.458	.838	.636	.835
	ZC_Q48	.808	***	.653	10.910			
	ZC_Q49	.881		.776				
Organisational readiness	ZD_Q50	.875	***	.766	12.530	.929	.767	.858
	ZD_Q52	.932	***	.868	12.530			
	ZD_Q54	.927		.860	12.455			
	ZD_Q55	.757		.573				
Social motivations	ZE_Q61	.903	***	.815	11.375	.874	.699	.870
	ZE_Q63	.854	***	.729	11.117			
	ZE_Q65	.744		.553				
Organisational culture	ZF_Q66	.837	***	.701	8.387	.862	.559	.841
	ZF_Q67	.763	***	.582	7.915			
	ZF_Q68	.798	***	.637	8.153			
	ZF_Q69	.709		.503	7.525			
	ZF_Q70	.611		.374				
Willingness /intention	ZG_Q71	.857	***	.734	12.063	.881	.649	.825
	ZG_Q72	.815	***	.664	11.446			
	ZG_Q74	.755	***	.570	10.457			
	ZG_Q75	.793		.629				
Organisation size	ZH_Q76	.981	***	.962	8.071	.924	.860	.921
	ZH_Q77	.870		.757				

**** = 0.001; S.M.C: Squared Multiple Correlation; AVE: Average variance extracted*

Table 5.5 The results of first-order factor analysis measurement models

Constructs	**Model Fit Indices**				
	CMIN/DF	**CFI**	**RMR**	**RMSEA**	**PCLOSE**
External environment characteristics	1.979	0.931	0.0632	0.075	0.014
Innovation characteristics	1.578	0.929	0.0601	0.068	0.185
Internal environment characteristics	1.177	0.980	0.0460	0.032	0.995

Table 5.6 Inter-correlation matrix of discriminant validity for the external environment characteristics

Constructs	Coercive pressures	Mimetic pressures	Normative pressures
Coercive pressures	**0.713**		
Mimetic pressures	0.453	**0.763**	
Normative pressures	0.500	0.391	**0.713**

The square root of average variance extracted ***(diagonal)*** *of each construct and correlation with other constructs (****off-diagonal)***

Table 5.7 Inter-correlation matrix of discriminant validity for the innovation characteristics

Constructs	Relative advantage	Compatibility	Complexity	Trialability	Observability	Technological factors
Relative advantage	**0.707**					
Compatibility	0.165	**0.815**				
Complexity	0.162	0.218	**0.801**			
Trialability	0.286	-0.081	-0.019	**0.753**		
Observability	0.380	0.331	0.280	0.200	**0.739**	
Technological factors	0.146	0.102	0.056	0.299	0.227	**0.674**

*The square root of average variance extracted (****diagonal****) of each construct and correlation with other constructs (****off-diagonal)***

Table 5.8 Inter-correlation matrix of discriminant validity for the internal environment characteristics

Construct	Top management support	Communication behaviour	Financial resources	Organisational readiness	Social motivations	Organisational culture	Willingness /intention	Organisation size
Top management support	**0.852**							
Communication behaviour	0.369	**0.808**						
Financial resources	0.367	0.349	**0.797**					
Organisational readiness	0.273	0.389	0.233	**0.876**				
Social motivations	0.376	0.253	0.185	0.216	**0.836**			
Organisational culture	0.082	0.052	0.299	0.246	0.328	**0.748**		
Willingness /intention	0.291	0.147	0.198	0.234	0.330	0.419	**0.806**	
Organisation size	0.268	0.128	0.194	0.224	0.207	0.264	0.180	**0.927**

*The square root of average variance extracted (**diagonal**) of each construct and correlation with other constructs (**off-diagonal**)*

5.7 Developing a Conceptual Model for investigating BIM adoption by organisations

"The analysis and synthesis of the SRL findings are used to develop a conceptual model for the empirical investigation of the BIM adoption process within organisations. The model merges together an adapted view of the innovation adoption process by Rogers (2003) and key conceptual constructs of the Innovation Diffusion Theory (IDT) and Institutional Theory (INT) (Figure 5.20) (Ahmed and Kassem, 2018, p.110).

"The IDT provides the theoretical requisites for investigating the effect of both the BIM characteristics (i.e., innovation attributes) and the organisation's internal environment characteristics (i.e., adopter or organisation readiness) on the BIM adoption process. The INT will help to investigate the effect of the external environment characteristics (i.e. institutional isomorphic pressures). The interactions between the constructs from the IDT and INT on the adoption process are illustrated in Figure 5.20. The awareness stage (Stage I) occurs when an organisation or a decision-making unit is exposed to a new innovation (i.e. BIM) and starts to gain knowledge about it. This stage may be triggered by some of the internal environment characteristics (e.g., communication behaviour, social motivations, organisational culture, and innovation willingness) as suggested by Rogers (2003) and/or by a combination of innovation, internal and external environment characteristics (e.g., coercive pressures, mimetic pressures, normative pressures, and market forces) characteristics (Hameed et al. (2012). However, systematic studies that investigate the effects of all these constructs on BIM innovation are still lacking" (Ahmed and Kassem, 2018, p.110).

The "intention/interest to adopt stage (Stage II) unfolds when an organisation or a decision-making unit develops a favourable or an unfavourable attitude towards the innovation. It is mainly affected by the perceived characteristics of the innovation (i.e., perceived usefulness, perceived ease of use, relative advantage, compatibility, complexity, trialability, observability, and technological factors) as suggested by Rogers (2003) but it can also be affected by the combination of factors associated with innovation, organisational, and external environment characteristics (Hameed et al. (2012)" (Ahmed and Kassem, 2018, p.111).

The "decision to adopt stage (Stage III) starts after the organisation (or organisation unit) has developed a favourable attitude towards the BIM innovation - or one of its specific stages - and it signals the start of a wilful set of experimental activities to implement the BIM innovation. At the end of this stage, the organisation might accept or reject the innovation. Studies establishing the factors that influence this stage are lacking, even in the seminal work on innovation adoption by Rogers (2003). In particular BIM-specific studies on innovation adoption have not differentiated between the stages of BIM adoption and have not considered an extensive number of drivers and factors in their investigations" (Ahmed and Kassem, 2018, p.111).

The "implementation stage (Stage IV) occurs when an organisation or a decision-making unit starts using the innovation - or one of its specific capability stages - in real world projects following the successful experimental implementation activities at Stage III. Finally, the confirmation stage (Stage V) is reached when an organisation or a decision-making unit requests support to further diffuse the adopted BIM innovation - or one of its specific capability stages - across its adopter population" (Ahmed and Kassem, 2018, p.111).

"Due to the peculiarities of BIM being an innovation entailing multiple capabilities stages [i.e. modelling, collaboration, and integration as established by (Succar, 2009)], the adoption stages (i.e. Stage I to Stage V) can iteratively unfold in cycles within an organisation or a decision-making unit for each BIM capability stage (i.e. modelling, collaboration, and integration) (Ahmed et al., 2017).

"This model will be used to conduct a retrospective analysis of BIM adoption within a market (i.e. the United Kingdom) by considering a sample of organisations that have already confirmed BIM adoption and crossed Stage III. Hence, the empirical investigation is focussed on the first three stages of the BIM adoption process" (Ahmed and Kassem, 2018, p.111).

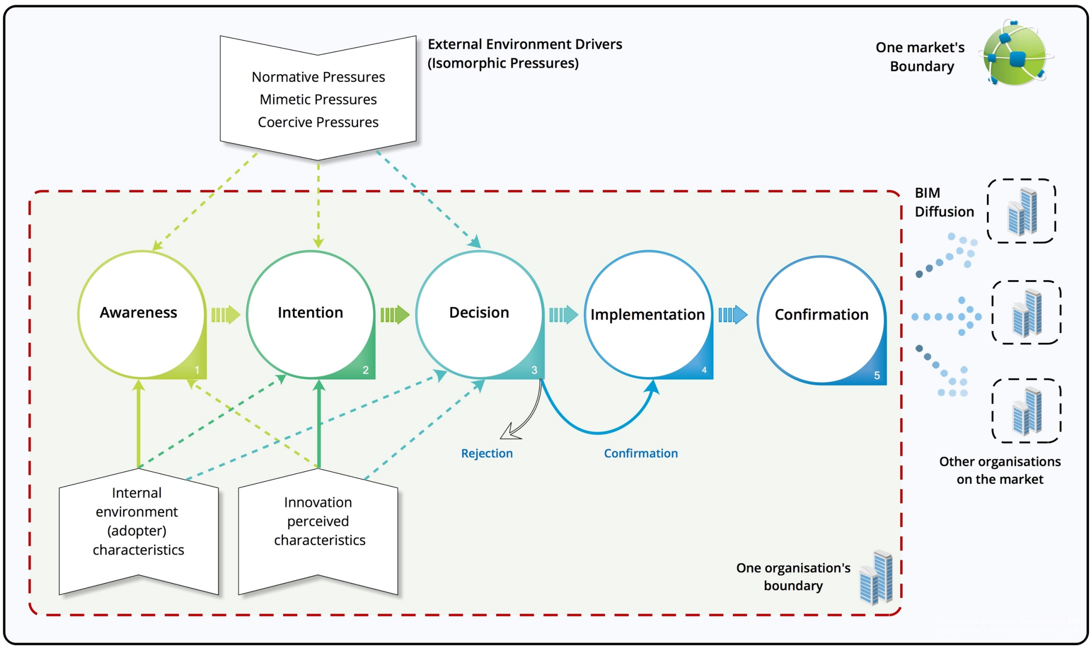


Figure 5.20 Conceptual Model for investigating BIM adoption decisions [adapted from Rogers's (2003)]

5.8 Summary and Conclusion

In this chapter, a Taxonomy of BIM Adoption and "a conceptual model for investigating BIM adoption decision by organisations was developed. First, the most widely used key terms and concepts explaining the diffusion of innovation processes were demonstrated. Second, the BIM Adoption Taxonomy was proposed in the form of three hierarchical taxonomy levels (i.e., clusters) covering drivers, factors and determinants of BIM adoption (*BIM innovation characteristics*; the *external environment characteristics*, and the *internal environment characteristics*). Third, the 17 constructs/factors of the proposed taxonomy were further examined in light of the prior literature on how the innovation (e.g., BIM and ICT/IS innovations) adoption by organisations was influenced by these constructs. Fourth, Confirmatory Factor Analysis was used to empirically evaluate and validate the measurement models that represent the taxonomy's constructs, which are developed in the form of Structural Equation Modelling (SEM). The validation of the proposed BIM adoption taxonomy was achieved by evaluating the validity and reliability of proposed CFA measurement models" (Ahmed and Kassem, 2018, p.106). Finally, the Systematic Literature Review findings and the developed taxonomy were used to develop a conceptual model for the empirical investigation of the BIM adoption process within organisations. Hence, Objective 2 of this study is achieved.

Having achieved this objective – in the next step, "this conceptual model will be used to conduct a retrospective analysis of BIM adoption within a market (i.e., the United Kingdom) by considering a sample of organisations that have already confirmed BIM" (Ahmed and Kassem, 2018, p.106).

Chapter 6 | The most influencing drivers and factors affecting the decision to adopt BIM by architectural organisations in the UK

6.1 Introduction

This chapter aims to achieve the third objective (Objective 3) of this study:

"*To understand the effect of the taxonomy's drivers and factors on the BIM adoption by Architecture practices within the United Kingdom by identifying the most influencing drivers and factors on each of the three adoption stages (i.e., awareness, interest, and decision to adopt) and analysing their comparative influence*" (Ahmed and Kassem, 2018, p.105)

The BIM adoption conceptual model – which is developed in the previous chapter – "will be used to conduct a retrospective analysis of BIM adoption within a market (i.e. the United Kingdom) by considering a sample of organisations that have already confirmed BIM adoption and crossed Stage III (i.e., Decision stage). Thus, the empirical investigation is focussed on the first three stages of the BIM adoption process (i.e., Awareness, Intention, and Decision)" (Ahmed and Kassem, 2018, p.111).

Figure 6.1 shows a roadmap of Chapter 6 in achieving Objective 3 of the study.

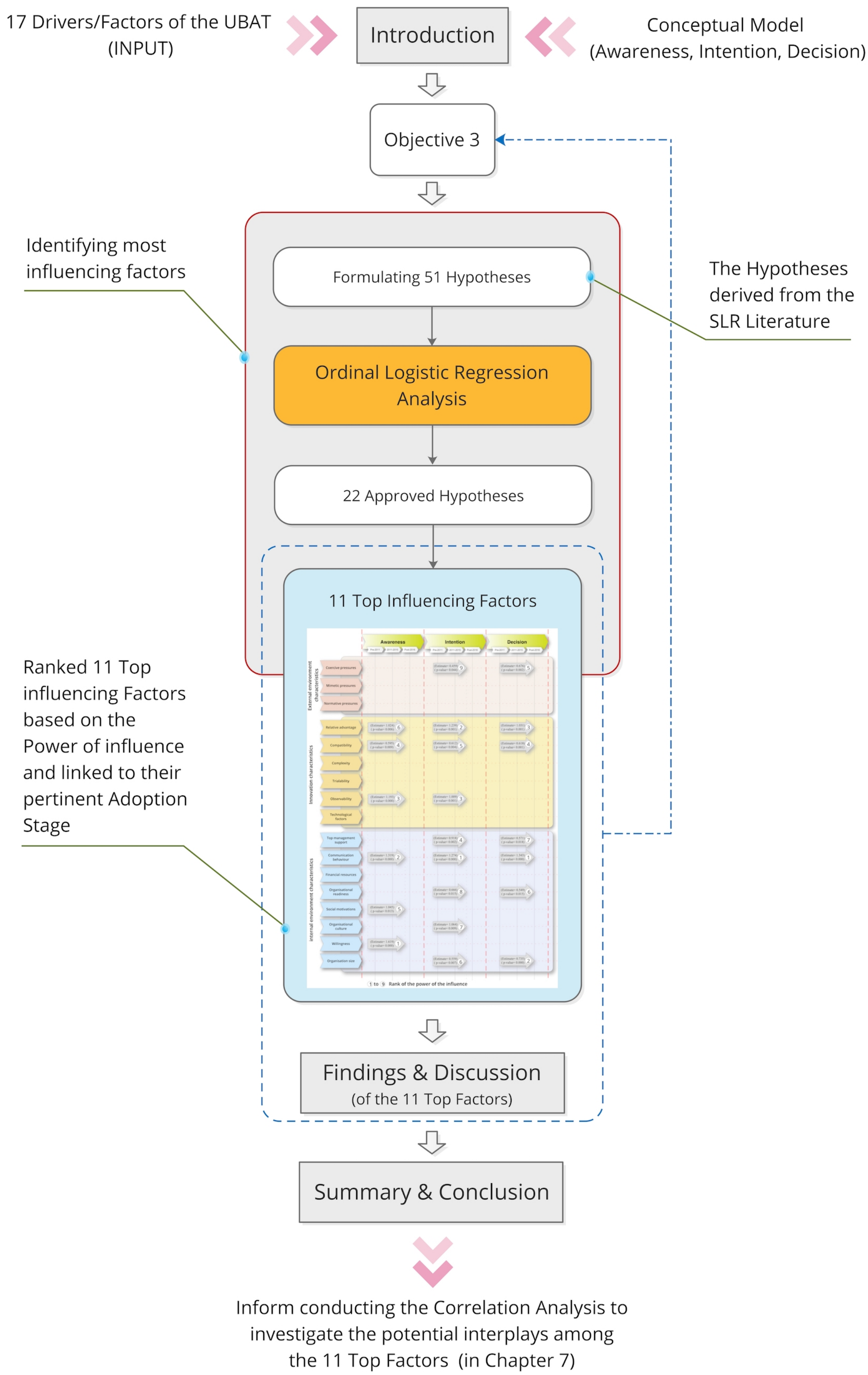


Figure 6.1 A roadmap of Chapter 6 in achieving Objective 3 of the study

6.2 Hypotheses

This section formulates hypotheses of the most influencing BIM adoption factors and, then, perform the testing of hypotheses.

6.2.1 Hypotheses formulation

Having developed the BIM Adoption Taxonomy and the BIM adoption conceptual model, this study has proposed a set of hypotheses to investigate and identify the most influencing drivers and factors in the process of BIM adoption and their power of the influence. These hypotheses were derived from the SLR findings and the taxonomy's constructs and their pertinent literature. "51 hypotheses (i.e. 17 constructs × 3 adoption stages) were formulated and grouped into three main clusters of drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics). Each main cluster (i.e., driver) includes a number of factors (i.e., constructs), of which each factor has three hypotheses one for each of the interval stages (ordinal) of the proposed BIM adoption conceptual model (i.e., awareness, intention, and decision). These 51 hypotheses postulate relationship effects between each of the 17 factors of the driver clusters and the three adoption stages partly based on the previous literature. However, all the reviewed studies did not provide a granular level of how each of the influencing factors affects each of the three stages (i.e., awareness, intention, and decision)" (Ahmed and Kassem, 2018, p.108) apart from disjointedly identifying and referring to the influence of these factors on the behavioural intention to adopt an innovation. Table 6.1 illustrates the development of the proposed hypotheses.

Table 6.1 The proposed Hypotheses of the potential influencing factors on each of the three stages (i.e., awareness, intention, and decision)

Drivers	Constructs/Factors	Hypotheses	Code
External environment characteristics	Coercive pressures	Architectural organisations which are subjected to coercive pressures are more likely to be aware of BIM.	H1
		Architectural organisations which are subjected to coercive pressures are more likely to be interested in adopting BIM.	H2
		Architectural organisations which are subjected to coercive pressures are more likely to be decided to adopt BIM.	H3
	Mimetic pressures	Architectural organisations which are subjected to mimetic pressures are more likely to be aware of BIM.	H4
		Architectural organisations which are subjected to mimetic pressures are more likely to be interested in adopting BIM.	H5
		Architectural organisations which are subjected to mimetic pressures are more likely to be decided to adopt BIM.	H6
	Normative pressures	Architectural organisations which are subjected to normative pressures are more likely to be aware of BIM.	H7
		Architectural organisations which are subjected to normative pressures are more likely to be interested in	H8
		Architectural organisations which are subjected to normative pressures are more likely to be decided to adopt	H9
Innovation characteristics	Relative advantage	Relative advantage has an effect on the diffusion of BIM awareness among the architectural organisations.	H10
		Relative advantage has an effect on the intention/interest of the architectural organisations to adopt BIM.	H11
		Relative advantage has an effect on the architectural organisations' decision to adopt BIM.	H12
	Compatibility	Compatibility has an effect on the diffusion of BIM awareness among the architectural organisations.	H13
		Compatibility has an effect on the intention/interest of the architectural organisations to adopt BIM.	H14
		Compatibility has an effect on the architectural organisations' decision to adopt BIM.	H15
	Complexity	Complexity has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H16
		Complexity has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	H17
		Complexity has a positive effect on the architectural organisations' decision to adopt BIM.	H18
	Trialability	Trialability has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H19
		Trialability has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	H20
		Trialability has a positive effect on the architectural organisations' decision to adopt BIM.	H21
	Observability	Observability has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H22
		Observability has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	H23
		Observability has a positive effect on the architectural organisations' decision to adopt BIM.	H24
	Technological factors	Technological factors have a positive effect on the diffusion of BIM awareness among the architectural organisations.	H25
		Technological factors have a positive effect on the intention/interest of the architectural organisations to	H26
		Technological factors have a positive effect on the architectural organisations' decision to adopt BIM.	H27
Internal environment characteristics	Top management support	Top management support has a positive effect on the diffusion of BIM awareness among the architectural	H28
		Top management support has a positive effect on the intention/interest of the architectural organisations to	H29
		Top management support has a positive effect on the architectural organisations' decision to adopt BIM.	H30
	Communication behaviour	Communication behaviour has a positive effect on the diffusion of BIM awareness among the architectural	H31
		Communication behaviour has a positive effect on the intention/interest of the architectural organisations to	H32
		Communication behaviour has a positive effect on the architectural organisations' decision to adopt BIM.	H33
	Financial resources	Financial resources have a positive effect on the diffusion of BIM awareness among the architectural organisations.	H34

		Financial resources have a positive effect on the intention/interest of the architectural organisations to	H35
		Financial resources have a positive effect on the architectural organisations' decision to adopt BIM.	H36
	Organisational readiness	Organisational readiness has a positive effect on the diffusion of BIM awareness among the architectural	H37
		Organisational readiness has a positive effect on the intention/interest of the architectural organisations to	H38
		Organisational readiness has a positive effect on the architectural organisations' decision to adopt BIM.	H39
	Social motivations	Social motivations have a positive effect on the diffusion of BIM awareness among the architectural organisations.	H40
		Social motivations have a positive effect on the intention/interest of the architectural organisations to	H41
		Social motivations have a positive effect on the architectural organisations' decision to adopt BIM.	H42
	Organisational culture	Organisational culture has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H43
		Organisational culture has a positive effect on the intention/interest of the architectural organisations to	H44
		Organisational culture has a positive effect on the architectural organisations' decision to adopt BIM.	H45
	Willingness	Willingness has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H46
		Willingness has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	H47
		Willingness has a positive effect on the architectural organisations' decision to adopt BIM.	H48
	Organisation size	Organisation size has a positive effect on the diffusion of BIM awareness among the architectural organisations.	H49
		Organisation size has a positive effect on the intention/interest of the architectural organisations to	H50
		Organisation size has a positive effect on the architectural organisations' decision to adopt BIM.	H51

6.2.2 Hypotheses Testing

To test the study hypotheses, Ordinal Logistic Regression was employed. It is used for investigating the relationship (i.e., effect) of an independent variable or a set of independent variables on an ordinal dependent variable (Brant, 1990; Harrell Jr, 2015). This test will investigate the influence of the 17 factors (i.e., independent variables) on the behaviours of the architectural organisations in shaping their reactions towards the decision to adopt BIM (i.e., dependent variable) at each of the three stages. The "aim is to provide a granular investigation of BIM adoption not only through the identification the factors that affect each adoption stage, but also through ranking the effect of influencing factors at each stage. The level of significance of each influencing factor is measured by comparing the *P-value* for the term (i.e., factor/construct) to the significance level of the null hypothesis (i.e. no association between the term and the response). The significance threshold (denoted as α or alpha) is 0.05 maximum, leaving a 5% risk of concluding that an association exists when there is not an actual association (Harrell, 2001)" (Ahmed and Kassem, 2018, p.108).

6.2.2.1 External environment characteristics

As shown in Table 6.2, the ordinal logistic regression results of the **External environment characteristics** at the '**Awareness**' stage were found to be not statistically significant. "Hence, there is no significant effect of the coercive pressures, mimetic pressures, and normative pressures on the awareness of BIM. Thus, the three hypotheses, (H1) '*Architectural organisations which are subjected to higher coercive pressures are more likely to be aware of BIM*'; (H4) '*Architectural organisations which are subjected to higher mimetic pressures are more likely to be aware of BIM*'; and (H7) '*Architectural organisations which are subjected to higher normative pressures are more likely to be aware of BIM*', were rejected/unsupported" (Ahmed and Kassem, 2018, p.109).

Table 6.2 Ordinal Logistic Regression results of the External Environment Characteristics constructs/factors at the Awareness stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Awareness = 1]	1.337	.975	1.880	1	.170	-.574	3.249
	[BIM_Awareness = 2]	5.417	1.206	20.170	1	.000	3.053	7.780
Location	Coercive_pressures	.120	.217	.307	1	.580	-.305	.545
	Mimetic_pressures	.138	.228	.363	1	.547	-.310	.585
	Normative_pressures	.003	.235	.000	1	.991	-.458	.463

Link function: Logit.

At the '**Intention/adoption interest**' stage, the effect of Coercive pressures on intention/interest attitude was found to be positive and significant (Estimate= 0.459, p-value= 0.044). "[Hence, hypothesis (H2) '*Architectural organisations which are subjected to higher coercive pressures are more likely to be interested in adopting BIM*' is supported. Also, the results showed that the other two factors (i.e., mimetic pressures and normative pressures) were not statistically significant. Accordingly, the two hypotheses were rejected: (H5) '*Architectural organisations which are subjected to higher mimetic pressures are more likely to be interested in adopting BIM*'; and (H8)

'*Architectural organisations which are subjected to higher normative pressures are more likely to be interested in adopting BIM*']" (Ahmed and Kassem, 2018, p.109) (Table 6.3).

Table 6.3 Ordinal Logistic Regression results of the External Environment Characteristics constructs/factors at the Intention/adoption interest stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Intention = 1]	-.298	.982	.092	1	.762	-2.223	1.627
	[BIM_Intention = 2]	3.696	1.041	12.599	1	.000	1.655	5.736
Location	Coercive_pressures	.459	.228	4.047	1	.044	.012	.907
	Mimetic_pressures	-.105	.239	.192	1	.661	-.573	.363
	Normative_pressures	-.121	.249	.239	1	.625	-.609	.366

Link function: Logit.

At the '**Decision**' stage, similarly, the effect of Coercive pressures on adoption decision attitude was found to be positive and significant (Estimate= 0.676, p-value= 0.002). "[Hence, hypothesis (H3) '*Architectural organisations which are subjected to higher coercive pressures are more likely to decide to adopt BIM*' is supported. Also, the results showed that the other two factors (i.e., mimetic pressures and normative pressures) were not statistically significant. Accordingly, the two hypotheses were rejected: (H6) '*Architectural organisations which are subjected to higher mimetic pressures are more likely to decide to adopt BIM*'; and (H9) '*Architectural organisations which are subjected to higher normative pressures are more likely to decide to adopt BIM*']" (Ahmed and Kassem, 2018, p.109) (Table 6.4).

Table 6.4 Ordinal Logistic Regression results of the External Environment Characteristics constructs/factors at the Decision stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Adoption_Decisio	-.548	.928	.349	1	.555	-2.366	1.270
	[BIM_Adoption_Decisio	2.475	.952	6.758	1	.009	.609	4.342
Location	Coercive_pressures	.676	.218	9.654	1	.002	.250	1.102
	Mimetic_pressures	-.193	.221	.764	1	.382	-.625	.239
	Normative_pressures	-.182	.230	.627	1	.428	-.634	.269

Link function: Logit.

6.2.2.2 Innovation (BIM) characteristics

Regarding the **Innovation characteristics**, the ordinal logistic regression results at the '**Awareness**' stage showed that three factors: Relative advantage, Compatibility, and Observability, positively and significantly influenced the awareness of BIM. The results were (Estimate= 1.024, p-value= 0.006), (Estimate= 0.595, p-value= 0.009), and (Estimate= 1.193, p-value= 0.000) respectively. These results lead to accepting three hypotheses: (H10) '*Relative advantage has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H13) '*Compatibility has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; and (H22) '*Observability has a positive effect on the diffusion of BIM awareness among the architectural organisations*'. However, the results showed that the other three factors (i.e., Complexity, Trialability, and Technical factors) were not statistically significant. Accordingly, three hypotheses were rejected: (H16) '*Complexity has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H19) '*Trialability has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; and (H25) '*Technological factors have a positive effect on the diffusion of BIM awareness among the architectural organisations*' (Table 6.5).

Table 6.5 Ordinal Logistic Regression results of the Innovation characteristics constructs/factors at the Awareness stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Awareness = 1]	9.172	2.043	20.163	1	.000	5.169	13.176
	[BIM_Awareness = 2]	13.876	2.284	36.903	1	.000	9.399	18.353
Location	Relative_advantage	1.024	.373	7.544	1	.006	.293	1.755
	Compatibility	.595	.227	6.883	1	.009	.151	1.040
	Complexity	-.200	.212	.885	1	.347	-.616	.216
	Trialability	-.004	.238	.000	1	.987	-.471	.463
	Observability	1.193	.340	12.298	1	.000	.526	1.859
	Technological_Factor	-.472	.251	3.538	1	.060	-.964	.020

Link function: Logit.

At the '**Intention/adoption interest**' stage, interestingly, the results showed that the same three factors: Relative advantage, Compatibility, and Observability, positively and significantly affected the intention/interest attitude towards BIM. The results were (Estimate= 1.239, p-value= 0.001), (Estimate= 0.612, p-value= 0.004), and (Estimate= 1.009, p-value= 0.001) respectively. These results supported three hypotheses: (H11) '*Relative advantage has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H14) '*Compatibility has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; and (H23) '*Observability has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'. Furthermore, the results showed that the other three factors (i.e., Complexity, Trialability, and Technical factors) were not statistically significant. Hence, three hypotheses were rejected: (H17) '*Complexity has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H20) '*Trialability has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; and (H26) '*Technological factors have a positive effect on the intention/interest of the architectural organisations to adopt BIM*' (Table 6.6).

Table 6.6 Ordinal Logistic Regression results of the Innovation characteristics constructs/factors at the Intention/adoption interest stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Intention = 1]	9.358	2.019	21.489	1	.000	5.402	13.315
	[BIM_Intention = 2]	14.537	2.285	40.491	1	.000	10.059	19.015
Location	Relative_advantage	1.239	.358	12.012	1	.001	.538	1.940
	Compatibility	.612	.211	8.443	1	.004	.199	1.025
	Complexity	.369	.211	3.062	1	.080	-.044	.782
	Trialability	-.422	.247	2.925	1	.087	-.906	.062
	Observability	1.009	.292	11.909	1	.001	.436	1.582
	Technological_Factors	-.048	.249	.037	1	.848	-.536	.440

Link function: Logit.

At the '**Decision**' stage, only two factors of the innovation characteristics: Relative advantage and Compatibility, positively and significantly affected the adoption decision attitude towards BIM. The results were (Estimate= 1.031, p-value= 0.001) and (Estimate= 0.618, p-value= 0.001) respectively. Thus, two hypotheses were accepted:

(H12) '*Relative advantage has a positive effect on the architectural organisations' decision to adopt BIM*'; and (H15) '*Compatibility has a positive effect on the architectural organisations' decision to adopt BIM*'. However, the results showed that the other four factors (i.e., Complexity, Trialability, Observability, and Technical factors) were not statistically significant. Hence, four hypotheses were rejected: (H18) '*Complexity has a positive effect on the architectural organisations' decision to adopt BIM*'; (H21) '*Trialability has a positive effect on the architectural organisations' decision to adopt BIM*'; (H24) '*Observability has a positive effect on the architectural organisations' decision to adopt BIM*'; and (H27) '*Technological factors have a positive effect on the architectural organisations' decision to adopt BIM*' (Table 6.7).

Table 6.7 Ordinal Logistic Regression results of the Innovation characteristics constructs/factors at the Decision stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Adoption_Decisio	5.437	1.597	11.591	1	.001	2.307	8.567
	[BIM_Adoption_Decisio	8.886	1.711	26.960	1	.000	5.532	12.241
Location	Relative_advantage	1.031	.311	10.966	1	.001	.421	1.642
	Compatibility	.618	.188	10.818	1	.001	.250	.986
	Complexity	.204	.183	1.237	1	.266	-.155	.563
	Trialability	-.199	.209	.903	1	.342	-.609	.212
	Observability	.361	.241	2.241	1	.134	-.112	.834
	Technological_Factors	-.178	.215	.682	1	.409	-.600	.244

Link function: Logit.

6.2.2.3 Internal environment characteristics

Regarding the **Internal environment characteristics**, the ordinal logistic regression results at the '**Awareness**' stage showed that three factors: Communication behaviour, Social motivations, and Willingness, positively and significantly influenced the awareness of BIM. The results were (Estimate= 1.319, p-value= 0.000), (Estimate= 1.054, p-value= 0.013), and (Estimate= 1.619, p-value= 0.000) respectively. Accordingly, three hypotheses were accepted: (H31) '*Communication behaviour has a* *positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H40) '*Social motivations have a positive effect on the diffusion of BIM awareness among the architectural organisations*'; and (H46) '*Willingness has a positive effect on the diffusion of BIM awareness among the architectural organisations*'. While, the results showed that the other five factors "(i.e., Top management support, Financial resources, Organisational readiness, Organisational culture, and Organisation size)" (Ahmed and Kassem, 2018, p.106) were not statistically significant. Hence, five hypotheses were rejected: (H28) '*Top management support has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H34) '*Financial resources have a positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H37) '*Organisational readiness has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; (H43) '*Organisational culture has a positive effect on the diffusion of BIM awareness among the architectural organisations*'; and (H49) 'Organisation size has a positive effect on the diffusion of BIM awareness among the architectural organisations' (Table 6.8).

Table 6.8 Ordinal Logistic Regression results of the Internal environment characteristics constructs/factors at the Awareness stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Awareness = 1]	14.183	2.492	32.401	1	.000	9.299	19.067
	[BIM_Awareness = 2]	19.284	2.793	47.668	1	.000	13.810	24.759
Location	Top_management_support	.024	.288	.007	1	.933	-.540	.588
	Communication_behaviour	1.319	.335	15.534	1	.000	.663	1.975
	Financial_resources	-.290	.245	1.400	1	.237	-.771	.191
	Organisational_readiness	.280	.273	1.046	1	.306	-.256	.815
	Social_motivations	1.054	.424	6.171	1	.013	.222	1.886
	Organisational_culture	-.718	.406	3.128	1	.077	-1.513	.078
	Willingness_intention	1.619	.411	15.515	1	.000	.813	2.425
	Organisation_sz	.140	.185	.567	1	.452	-.224	.503

Link function: Logit.

At the '**Intention/adoption interest**' stage, the results showed that five factors: "Top management support, Communication behaviour, Organisational readiness, Organisational culture" (Ahmed and Kassem, 2018, p.106), and Organisation size, positively and significantly affected the intention/interest attitude towards BIM. The results were (Estimate= 0.918, p-value= 0.002), (Estimate= 1.274, p-value= 0.000), (Estimate= 0.666, p-value= 0.015), (Estimate= 1.064, p-value= 0.009) and (Estimate= 0.559, p-value= 0.007) respectively. These results supported five hypotheses: (H29) '*Top management support has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H32) '*Communication behaviour has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H38) '*Organisational readiness has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H44) '*Organisational culture has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; and (H50) '*Organisation size has a positive effect on the intention/interest of the architectural organisations to adopt BIM*'. Furthermore, the results showed that the other three factors (i.e., Financial resources, Social motivations, and Willingness) were not statistically significant. Hence, three hypotheses were rejected: (H35) '*Financial resources have a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; (H41) '*Social motivations have a positive effect on the intention/interest of the architectural organisations to adopt BIM*'; and (H47) '*Willingness has a positive effect on the intention/interest of the architectural organisations to adopt BIM*' (Table 6.9).

Table 6.9 Ordinal Logistic Regression results of the Internal environment characteristics constructs/factors at the Intention/adoption interest stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Intention = 1]	15.459	2.483	38.755	1	.000	10.592	20.326
	[BIM_Intention = 2]	21.667	2.947	54.045	1	.000	15.890	27.444
Location	Top_management_support	.918	.301	9.329	1	.002	.329	1.508
	Communication_behaviour	1.274	.306	17.329	1	.000	.674	1.873
	Financial_resources	.112	.242	.213	1	.645	-.363	.587
	Organisational_readiness	.666	.273	5.938	1	.015	.130	1.201
	Social_motivations	.332	.406	.670	1	.413	-.464	1.128
	Organisational_culture	1.064	.406	6.883	1	.009	.269	1.859
	Willingness	-.322	.333	.933	1	.334	-.974	.331
	Organisation_sz	.559	.206	7.380	1	.007	.156	.962

Link function: Logit.

At the '**Decision**' stage, only four factors of the internal environment characteristics: "Top management support, Communication behaviour, Organisational readiness, and Organisation size" (Ahmed and Kassem, 2018, p.106), positively and significantly affected the adoption decision attitude towards BIM. The results were (Estimate= 0.571, p-value= 0.018), (Estimate= 1.343, p-value= 0.000), (Estimate= 0.549, p-value= 0.015) and (Estimate= 0.735, p-value= 0.000) respectively. Accordingly, four hypotheses were accepted: (H30) '*Top management support has a positive effect on the architectural organisations' decision to adopt BIM*'; (H33) '*Communication behaviour has a positive effect on the architectural organisations' decision to adopt BIM*'; (H39) '*Organisational readiness has a positive effect on the architectural organisations' decision to adopt BIM*'; and (H51) '*Organisation size has a positive effect on the architectural organisations' decision to adopt BIM*'.

Also, the results showed that the other four factors (i.e., Financial resources, Social motivations, Organisational culture, and Willingness) were not statistically significant. Hence, four hypotheses were rejected: (H36) '*Financial resources have a positive effect on the architectural organisations' decision to adopt BIM*'; (H42) '*Social motivations have a positive effect on the architectural organisations' decision to adopt BIM*'; (H45) '*Organisational culture has a positive effect on the architectural* *organisations' decision to adopt BIM*'; and (H48) '*Willingness has a positive effect on the architectural organisations' decision to adopt BIM*' (Table 6.10).

Table 6.10 Ordinal Logistic Regression results of Internal environment characteristics constructs/factors at the Decision to adopt BIM stage

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[BIM_Adoption_Decision = 1.00]	9.234	1.764	27.418	1	.000	5.778	12.691
	[BIM_Adoption_Decision = 2.00]	13.979	2.024	47.699	1	.000	10.012	17.947
Location	Top_management_support	.571	.242	5.564	1	.018	.097	1.046
	Communication_behaviour	1.343	.272	24.337	1	.000	.810	1.877
	Financial_resources	.376	.225	2.804	1	.094	-.064	.816
	Organisational_readiness	.549	.226	5.893	1	.015	.106	.993
	Social_motivations	.479	.325	2.173	1	.140	-.158	1.115
	Organisational_culture	-.317	.341	.868	1	.352	-.985	.350
	Willingness	-.486	.280	3.008	1	.083	-1.035	.063
	Organisation_sz	.735	.187	15.471	1	.000	.369	1.101

Link function: Logit.

Having conducted the Ordinal Logistic Regression analysis and demonstrated its results, 22 hypotheses out of the 51 were approved "that entailed 11 factors with positive and significant influence on the adoption stages. This analysis provides a granular investigation of BIM adoption process not only through the identification the factors that affect each adoption stage, but also through ranking the effect of influencing factors at each stage. Table 6.11 provides the hypotheses outcome of the most influential factors at each stage of the BIM adoption process" (Ahmed and Kassem, 2018, p.106).

Table 6.11 Hypotheses test Outcome

Constructs/Factors	Code	Hypotheses	Outcome
Coercive pressures	H1	Architectural organisations which are subjected to higher coercive pressures are more likely to be aware of BIM.	Rejected
	H2	Architectural organisations which are subjected to higher coercive pressures are more likely to be interested in adopting BIM.	Accepted
	H3	Architectural organisations which are subjected to higher coercive pressures are more likely to be decided to adopt BIM.	Accepted
Mimetic pressures	H4	Architectural organisations which are subjected to higher mimetic pressures are more likely to be aware of BIM.	Rejected
	H5	Architectural organisations which are subjected to higher mimetic pressures are more likely to be interested in adopting BIM.	Rejected
	H6	Architectural organisations which are subjected to higher mimetic pressures are more likely to be decided to adopt BIM.	Rejected
Normative pressures	H7	Architectural organisations which are subjected to higher normative pressures are more likely to be aware of BIM.	Rejected
	H8	Architectural organisations which are subjected to higher normative pressures are more likely to be interested in adopting BIM.	Rejected
	H9	Architectural organisations which are subjected to higher normative pressures are more likely to be decided to adopt BIM.	Rejected
Relative advantage	H10	Relative advantage has an effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H11	Relative advantage has an effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H12	Relative advantage has an effect on the architectural organisations' decision to adopt BIM.	Accepted
Compatibility	H13	Compatibility has an effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H14	Compatibility has an effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H15	Compatibility has an effect on the architectural organisations' decision to adopt BIM.	Accepted
Complexity	H16	Complexity has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H17	Complexity has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H18	Complexity has a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Trialability	H19	Trialability has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H20	Trialability has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H21	Trialability has a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Observability	H22	Observability has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H23	Observability has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H24	Observability has a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Technological factors	H25	Technological factors have a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H26	Technological factors have a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H27	Technological factors have a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Top management support	H28	Top management support has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H29	Top management support has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H30	Top management support has a positive effect on the architectural organisations' decision to adopt BIM.	Accepted
Communication behaviour	H31	Communication behaviour has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H32	Communication behaviour has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H33	Communication behaviour has a positive effect on the architectural organisations' decision to adopt BIM.	Accepted
Financial resources	H34	Financial resources have a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected

	H35	Financial resources have a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H36	Financial resources have a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Organisational readiness	H37	Organisational readiness has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H38	Organisational readiness has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H39	Organisational readiness has a positive effect on the architectural organisations' decision to adopt BIM.	Accepted
Social motivations	H40	Social motivations have a positive effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H41	Social motivations have a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H42	Social motivations have a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Organisational culture	H43	Organisational culture has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H44	Organisational culture has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H45	Organisational culture has a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Willingness	H46	Willingness has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Accepted
	H47	Willingness has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Rejected
	H48	Willingness has a positive effect on the architectural organisations' decision to adopt BIM.	Rejected
Organisation size	H49	Organisation size has a positive effect on the diffusion of BIM awareness among the architectural organisations.	Rejected
	H50	Organisation size has a positive effect on the intention/interest of the architectural organisations to adopt BIM.	Accepted
	H51	Organisation size has a positive effect on the architectural organisations' decision to adopt BIM.	Accepted

As can be seen from Figure 6.2, that the '**Awareness**' "stage was found to be affected by six factors related to the *organisational internal environment characteristics* and the *BIM innovation characteristics*. These factors are: *Willingness, Communication behaviour, Observability, Relative advantage, Compatibility*, and *Social motivations*. While the *organisation's internal environment characteristics* and the *BIM innovation characteristics* mutually affected the awareness of BIM, the *external environment characteristics/driver* (i.e., institutional pressures) had no significant effect on the awareness. The '**Intention**' stage was influenced by nine factors (i.e. *Communication behaviour, Relative advantage, Observability, Top management support, Compatibility, Organisation size, Organisational culture, Organisational readiness*, and *Coercive pressures*) from across the three driver clusters including *coercive pressure* as one of the *external environment drivers*. The '**Decision**' stage was influenced by seven factors (i.e. *Communication behaviour, Organisation size, Relative advantage, Compatibility, Coercive pressures, Organisational readiness,* and *Top management support*) from across the three driver clusters. Similar to the '**Intention**' stage, only *coercive pressures* had a positive and significant influence on the decision to adopt BIM by architectural organisations" (Ahmed and Kassem, 2018, p.111).

The illustrated results in Figure 6.2 "also rank the influence of the different factors on each stage of the adoption process. The ranking is expressed as the 'power of influence' of each factor and was ordered based on the lowest P-value (i.e., ≤0.05) and highest 'Estimate' value of the results of Ordinal Logistic Regression test. *Willingness* was the factor with the highest influence on the '**Awareness**' stage. *Communication behaviour* had the highest influence on both the '**Intention**' stage and the '**Decision**' stage" (Ahmed and Kassem, 2018, p.111).

These results represent "the effect of 'individual' driving factor on BIM adoption as identified by the Ordinal Logistic Regression analysis. However, the coexistence of different factors at each stage of the adoption process can result in new influences and dynamics. These interplays will be captured through correlation analysis tests" (Ahmed and Kassem, 2018, p.111) in the next chapter.

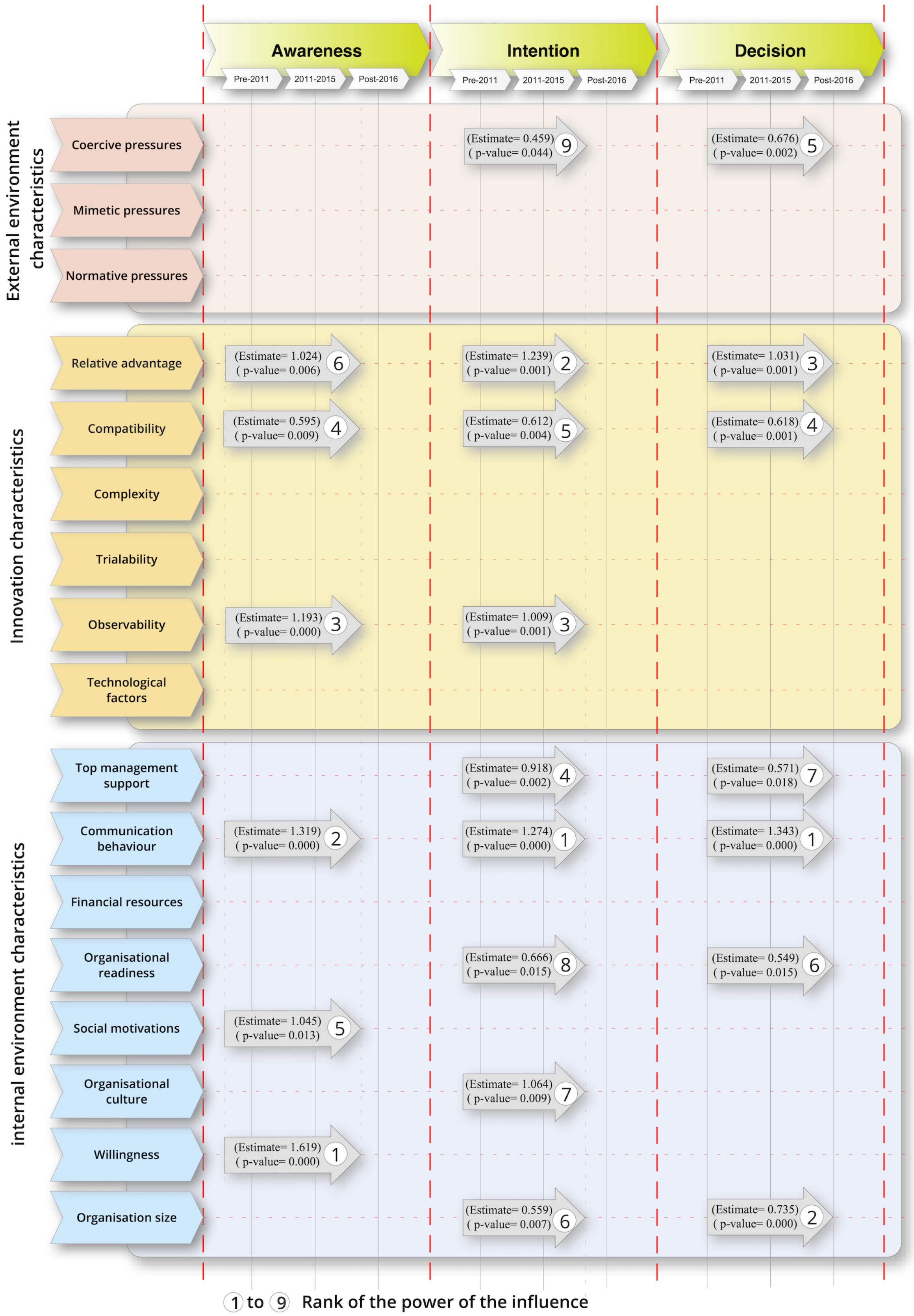


Figure 6.2 The results of the most influential factors at each stage of the BIM adoption process

6.3 Findings and discussion of the 11 most influencing factors on the stages of BIM adoption process

6.3.1 Willingness

At the '**Awareness**' stage, *Willingness* comes first in the rank of the power of influence of the six identified factors affecting this stage. Whereas at the '**Intention**' stage and the '**Decision**' stage, the results showed that the *Willingness* was not statistically significant. Therefore, it does not affect these two stages. This finding is consistent with Rogers (2003) innovation-decision process, who suggests that the organisation characteristics (i.e., internal environment characteristics) may trigger the organisations' *awareness* to gain more knowledge about the innovation. However, previous literature lacks such a granular level of investigation regarding the *Willingness* power of influence, apart from general identification of *Willingness* as one of the critical factors influencing innovation (e.g., BIM /ICT) adoption (Xu et al., 2014; Son et al., 2015; Kim et al., 2015) regardless the stage of its effect (Table 6.12).

6.3.2 Communication behaviour

Communication behaviour comes second in the rank (i.e., after *Willingness)* of the power of influence of the six identified factors affecting the '**Awareness**' stage. This finding is in agreement with Rogers (2003) findings whereas a little literature (e.g., Blayse and Manley, 2004; Gorse and Emmitt, 2007) has referred to the important influence of *Communication behaviour* on innovation adoption. While at both the '**Intention**' stage and the '**Decision**' stage, the results showed that *Communication behaviour* comes first in the rank of nine factors and seven factors respectively. This finding indicates the possibility of *Communication behaviour*, which belongs to the *internal environment characteristics*, to have an influence on other stages of BIM adoption process beyond what has been reported in previous literature (Table 6.12).

6.3.3 Observability

At the '**Awareness**' stage, *Observability* comes third in the rank (i.e., after *Communication behaviour*) of the power of influence of the six identified factors affecting this stage. Such finding points out to the possibility of *Observability*, which is a factor of the *innovation characteristics* to have an influence on another stage (i.e., Awareness) of BIM adoption process beyond the expected stage (i.e., Intention stage) that has been reported in previous literature (Rogers, 2003). At the '**Intention**' stage, similarly, *Observability* comes third – but after *Relative advantage* - in the rank of nine identified factors affecting this stage. This finding is in congruence with previous findings (i.e., Rogers, 2003) of which *Observability* promotes favourable attitude (i.e., intention) towards BIM adoption, besides the general identification of *Observability* as a critical factor influencing innovation adoption (e.g., Cope and Ward, 2002; Martins et al., 2004; Groff and Mouza, 2008) regardless the stage of its effect. While at the '**Decision**' stage, the results showed that the *Observability* factor was not statistically significant. Therefore, it has no effect on this stage (Table 6.12).

6.3.4 Compatibility

Compatibility comes fourth in the rank (i.e., after *Observability*) of the power of influence of the six identified factors affecting the '**Awareness**' stage. At the '**Intention**' stage, *Compatibility* comes fifth (i.e., after *Top management support*) in the rank of nine identified factors affecting this stage. This indicates that *Compatibility* promotes favourable attitude of organisations towards the innovation adoption (Rogers, 2003) and more specifically, identifying *Compatibility* as a critical factor affects the potential adopters' behavioural intention (i.e., Intention stage) to adopt BIM (Kim et al., 2015; Gu and London, 2010; Son et al., 2015; Davies and Harty, 2013; Gledson and Greenwood, 2017; Xu et al., 2014). At the '**Decision**' stage, *Compatibility* also comes fourth in the rank (i.e., after *Relative advantage*) of the seven identified factors affecting this stage. This finding (i.e., the *Compatibility* influence on both the 'Awareness' and 'Decision' stages) points out to that *innovation characteristics* may have an influence on other stages of BIM adoption process beyond the expected stage (i.e., Intention stage) (Table 6.12).

6.3.5 Social motivations

At the '**Awareness**' stage, Social motivations comes fifth in the rank of the power of influence of the six identified factors affecting this stage. While at the '**Intention**' stage and the '**Decision**' stage, the results showed that the *social motivations* factor does not affect these two stages. This finding seems to be consistent with Rogers (2003) innovation-decision process, who suggests that the organisation characteristics (i.e., internal environment characteristics) may only trigger the organisations' *awareness* to gain more knowledge about the innovation. However, a few studies (e.g., Singh and Holmstrom, 2015; Cao et al., 2016; Mom et al., 2014) has generally identified *social motivations* as one of the critical factors promoting technology (e.g., BIM /ICT) adoption decision by organisations regardless the stage of its effect (Table 6.12).

6.3.6 Relative advantage

At the '**Awareness**' stage, *Relative advantage* comes sixth in the rank (i.e., after *Social motivations*) of the power of influence of the six identified factors affecting this stage. The *Relative advantage* comes second (i.e., after *Communication behaviour*) in the rank of nine factors affecting the '**Intention**' stage. This indicates that *Relative advantage* promotes favourable attitude of organisations towards the innovation adoption (Rogers, 2003) and more specifically, identifying *Relative advantage* as a key characteristic that determines whether an innovation (e.g., BIM or ICT) is relatively advantageous through the estimated benefits (Oliveira et al., 2014), and influences the organisation's behavioural intention (i.e., Intention stage) to adopt an innovation (Tsai et al., 2010). At the '**Decision**' stage, *Relative advantage* also comes third in the rank (i.e., after *Organisation size*) of seven factors affecting this stage. This finding (i.e., the *Relative advantage* influence on both the 'Awareness' and 'Decision' stages) points out to that *innovation characteristics* may have an influence on other stages of BIM adoption process beyond the expected stage (i.e., Intention stage) (Table 6.12).

6.3.7 Organisational culture

At the '**Awareness**' stage, the results showed that the *Organisational culture* factor does not affect this stage. This finding is in disagreement with Rogers (2003) findings which showed that the organisation characteristics (i.e., *internal environment characteristics*) may only trigger the organisations' *awareness* of the innovation. At the '**Intention**' stage, *Organisational culture* comes seventh (i.e., after *Organisation size*) in the rank of nine factors affecting this stage. This finding is in congruence with previous findings of which generally identifying *Organisational culture* as a key factor affecting innovative IT/IS adoption and supply chain management practices (Stock et al., 2007; Khazanchi et al., 2007; Leidner and Kayworth, 2006; Yitmen, 2007). However, only one study by Liu et al. (2010a) – that found *Organisational culture* promotes firms' intention of BIM adoption – conforms to the current study finding regarding *Organisational culture* influence on the 'Intention' stage instead of the 'Awareness' stage. While at the '**Decision**' stage, the results showed that the *Organisational culture* factor does not affect this stage (Table 6.12).

6.3.8 Top management support

The results showed that the *Top management support* factor does not affect the '**Awareness**' stage. This indicates a disagreement with Rogers (2003) findings which showed that the organisation characteristics (i.e., *internal environment characteristics*) may only trigger the organisations' *awareness* of the innovation. At the '**Intention**' stage, *Top management support* comes fourth (i.e., after *observability*) in the rank of the power of influence of nine factors affecting this stage. This finding is consistent with previous studies identifying *Top management support* as one of the factors that critically affect the adoption and implementation of information technology and information systems innovations (Thong et al., 1996; Swink, 2000; Madanayake, 2014). In many BIM studies, *top management support* was cited as one of the key influencing factors in BIM adoption (e.g., Liu et al., 2010b; Hartmann et al., 2012; Son et al., 2015). However, only one study by Son et al. (2015) - that found *Top management support* plays a critical role affecting the behavioural intentions of the architectural firms towards BIM adoption – conforms to the current study finding regarding *Top management support* influence on the 'Intention' stage instead the 'Awareness' stage. At the '**Decision**' stage, *Top management support* comes seventh in the rank (i.e., after *Organisational readiness*) of seven factors affecting this stage. This finding "(i.e., the *Top management support* influence on both the 'Intention' and

‘Decision’ stages) points out that *internal environment characteristics* may have an influence on other stages of BIM adoption process beyond the expected stage (i.e., Awareness stage)” (Ahmed and Kassem, 2018, p.112) (Table 6.12).

6.3.9 Organisational readiness

At the ‘**Awareness**’ stage, the results showed that the *Organisational readiness* factor does not this stage. This finding is in disagreement with Rogers (2003) findings which showed that the organisation characteristics (i.e., *internal environment characteristics*) may only trigger the organisations’ *awareness* of an innovation. At the ‘**Intention**’ stage, *Organisational readiness* comes eighth (i.e., after *Organisational culture*) in the rank of nine identified factors this stage. This finding is consistent with previous studies identifying *Organisational readiness* as one of the critical success factors for IT/ICT innovation adoption (Mom et al., 2014; Tsai et al., 2010; Lai and Guynes, 1997; Subramanian and Nilakanta, 1996; Premkumar and Roberts, 1999; Shim et al., 2009; Premkumar and Ramamurthy, 1995). However, only two studies [i.e.,(Mom et al., 2014; Tsai et al., 2010)] - that found *Organisational readiness* promotes organisations’ intention of BIM adoption – conform to the current study finding. *Organisational readiness* comes sixth (i.e., after *Coercive pressures*) in the rank of seven factors affecting the ‘**Decision**’ stage. “This finding (i.e., the *Organisational readiness* influence on both the ‘Intention’ and ‘Decision’ stages) points out that *internal environment characteristics* may have an influence on other stages of BIM adoption process” (Ahmed and Kassem, 2018, p.112) beyond the expected stage (i.e., Awareness stage) (Table 6.12).

6.3.10 Coercive pressures

The results showed that the *Coercive pressures* factor does not affect the ‘**Awareness**’ stage. At the ‘**Intention**’ stage, *Coercive pressures* factor comes ninth (i.e., after *Organisational readiness*) in the rank of the power of influence of nine identified factors affecting this stage. This indicates that Coercive pressures (i.e., of external pressures) influence the process of innovation adoption – as proposed by Rogers (2003). More specifically, Coercive pressures drive companies to adopt similar organisational procedures and practices to conform to institutional and political legitimacy to secure their existence in a social network (DiMaggio and Powell, 1983; Krell et al., 2016; Tsai et al., 2013; Liu et al., 2010a; Cao et al., 2014). However, the current study has also identified that *Coercive pressures* – as a factor of the *external environment characteristics* – influences the '**Intention**' stage. At the '**Decision**' stage, *Coercive pressures* come fifth (i.e., after *Compatibility*) in the rank of seven factors affecting this stage. This finding (i.e., the *Coercive pressures* influence on both the 'Intention' and 'Decision' stages) points out that *external environment characteristics* may have an influence on other stages of BIM adoption (Table 6.12).

6.3.11 Organisation size

At the '**Awareness**' stage, the results showed that the *Organisation size* factor does not affect this stage. This indicates a disagreement with Rogers (2003) findings which showed that the organisation characteristics (i.e., *internal environment characteristics*) may only trigger the organisations' *awareness* of the innovation. *Organisation size* comes sixth (i.e., after *Compatibility*) in the rank of the power of influence of nine factors affecting the '**Intention**' stage. At the '**Decision**' stage, *Organisation size* comes second (i.e., after *Communication behaviour*) in the rank of seven factors affecting this stage. This finding conforms to the extant literature of how *organisation size* influence determines the organisations' innovation adoption aspirations (Jung and Lee, 2016; Shim et al., 2009); and, more specifically, how small firms have larger amounts of adaptability and capacity to adjust and progress. Hence, small firms can be more viable at adopting and implementing organisational innovation (Damanpour, 1992; Mintzberg, 1989). Therefore, the current study has clearly identified *organisation size* as a factor - of the *internal environment characteristics* - that influences "both the 'Intention' stage and 'Decision' stage instead of the 'Awareness' stage" (Ahmed and Kassem, 2018, p.112) according to the results (Table 6.12).

Table 6.12 Comparing the existence of the 11 most influencing factors between the literature and this study

Factors	Stages	Influence according to literature	Influence according to this study
Willingness/ intention	Awareness	✓	✓ (green)
	Intention	✗	✗ (green)
	Decision	✗	✗ (green)
Communication behaviour	Awareness	✓	✓ (green)
	Intention	✗	✓ (red)
	Decision	✗	✓ (red)
Observability	Awareness	✗	✓ (red)
	Intention	✓	✓ (green)
	Decision	✗	✗
Compatibility	Awareness	✗	✓ (red)
	Intention	✓	✓ (green)
	Decision	✗	✓ (red)
Social motivations	Awareness	✓	✓ (green)
	Intention	✗	✗ (green)
	Decision	✗	✗ (green)
Relative advantage	Awareness	✗	✓ (red)
	Intention	✓	✓ (green)
	Decision	✗	✓ (red)
Organisational culture	Awareness	✓	✗ (red)
	Intention	✓ (red)	✓ (red)
	Decision	✗	✗ (green)
Top management support	Awareness	✓	✗ (red)
	Intention	✓ (red)	✓ (red)
	Decision	✗	✓ (red)
Organisational readiness	Awareness	✓	✗ (red)
	Intention	✓ (red)	✓ (red)
	Decision	✗	✓ (red)
Coercive pressures	Awareness	✗	✗ (green)
	Intention	✓	✓ (green)
	Decision	✗	✓ (red)
Organisation size	Awareness	✓	✗ (red)
	Intention	✗	✓ (red)
	Decision	✗	✓ (red)

✗ ✓ As shown in literature   ✗ ✓ (red) Contrary to literature   ✗ ✓ (green) Study finding conforms to literature

6.4 Summary and Conclusion

In this chapter, "a set of the most influential factors affecting the decision to adopt BIM by the architectural organisations within the UK's market was identified and ranked based on their power of influence at each stage of the BIM adoption process. First, 51 hypotheses were formulated and grouped into three main clusters based on the three characteristics drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics). These hypotheses were derived from the SLR findings and the taxonomy's constructs and their pertinent literature. Second, the Ordinal Logistic Regression analysis was employed to test the study hypotheses postulating relationship effects between each of 17 factors of the driver clusters (i.e., of the Unified BIM Adoption Taxonomy) and the three adoption stages (i.e., awareness, intention, and decision)" (Ahmed and Kassem, 2018, p.112) based on BIM adoption process conceptual model that was developed in Chapter 5. "Out of the 51, 22 hypotheses were approved and resulted in 11 factors with positive and significant influence on the adoption stages. Third, these identified factors were further ranked based on their power of influence. Finally, the findings of the Ordinal Logistic Regression analysis (i.e., the findings of each of the identified factors) were demonstrated and discussed with reference to the prior literature" (Ahmed and Kassem, 2018, p.110).

The result of this analysis identified new influences by certain adoption factors – that belong to specific on stages that were not established in prior research. The results also showed that certain factors had an influence only on other stages instead of the expected ones (i.e., identified based on the literature). With the exception of the influence of the Coercive pressures (i.e., formal and informal mandate) on the 'Intention' and 'Decision' Stages, there was no evidence about the influence of both the 'mimetic pressures' and 'normative pressures' on the three stages.

In the next chapter, the top 11 factors will be further tested using Correlation Analysis to investigate the potential interplays among these factors while exerting an effect on the BIM adoption stage.

Chapter 7 | A Two-dimensional Characterisation Model of the BIM adoption process for the UK Architectural Organisations

7.1 Introduction

Following the identification of the 11 most influencing factors in the process of BIM adoption (in Chapter 6), this chapter aims to achieve the fourth objective (Objective 4) of this study:

"*To develop a two-dimensional characterisation model of BIM adoption including interplays between correlated pairs of adoption factors, and time (i.e., three time periods including pre-mandate period, implementation/trial period, and post-mandate period)*"

The first section identifies potential correlations among the 11 top influencing factors. The second section demonstrates and discusses the findings of the correlation analysis. The last section develops the Two-dimensional Characterisation Model for the BIM adoption process.

Figure 7.1 shows a roadmap of Chapter 7 in achieving Objective 4 of the study.

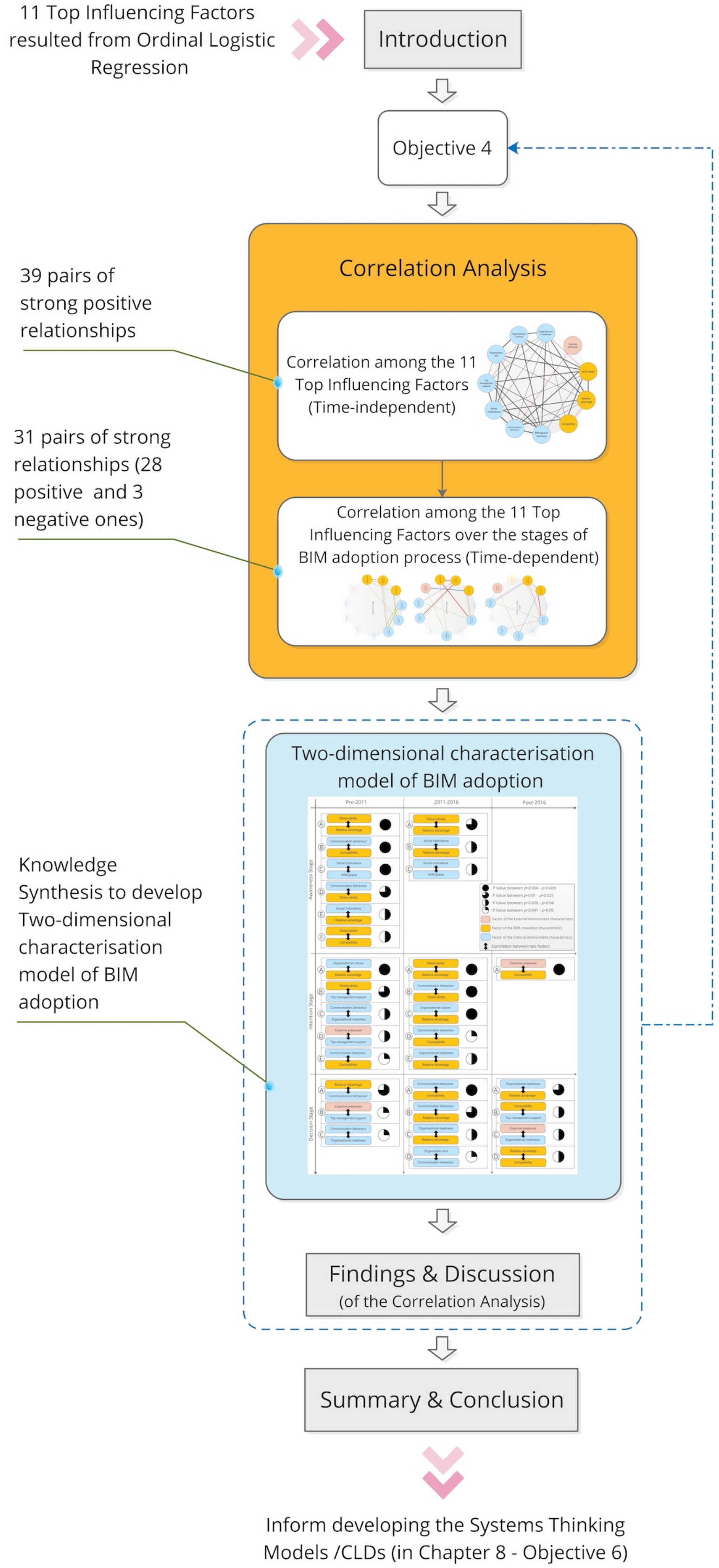


Figure 7.1 A roadmap of Chapter 7 in achieving Objective 4 of the study

7.2 Correlation Analysis

The results of the Ordinal Logistic Regression analysis were further used to inform two cycles of correlation analysis (1) to determine if there were any relationship among the most influencing factors in the process of BIM adoption, and (2) to assess in details the associations among the same factors separately at each stage (i.e., awareness, intention and decision to adopt) considering the time horizon of the UK BIM Strategy (i.e., pre-announcement of BIM mandate/pre-2011; trial implementation period of BIM mandate/2011-2016; and post-mandate/post-2016) (Ahmed and Kassem, 2018, p.105).

Since the data is non-parametric, *Spearman's rank correlation coefficient* analysis was used with a two-tailed significance test was adopted to test the possibility of the relationship (i.e., statistical dependence) between two variables in both directions (Jamieson, 2004). Spearman's coefficient usually denoted by '***rho***' or '***p***' and commonly used to assess the correlation of ordinal data (Field, 2013). Two values will be provided by running this test: the correlation 'r_s' and the significance '***p-value***'. Two sets of Spearman's correlation test were conducted in the following sections.

7.2.1 Correlation among the most influencing factors

As shown in Table 7.1, 11 factors, which were statistically identified as the most influencing factors in the process of BIM adoption – out of the 17 factors – were assessed for potential correlations among each other using Spearman's rank-order correlation coefficient test. "These factors were *Willingness, Communication behaviour, Observability, Relative advantage, Compatibility, Social motivations, Top management support, Organisation size, Organisational culture, Organisational readiness, and Coercive pressures*" (Ahmed and Kassem, 2018, p.104).

A set of two-tailed significance tests was performed among each pair of factors. The Correlations among the 11 most influencing factors resulted in a set of 39 pairs of strong positive relationships that were statistically significant. The results of the correlated factors are ranked and represented in Table 7.2 and Figure 7.2.

Table 7.1 Correlations among all the influencing factors

			Relative advantage	Compatibility	Observability	Top management support	Communication behaviour	Organisational readiness	Social motivations	Organisational culture	Willingness intention	Organisation size	Coercive pressures
Spearman's rho	Relative advantage	Correlation Coefficient	1.000	.165*	.418**	.090	.236**	.283**	.308**	.382**	.230**	.214**	.117
		Sig. (2-tailed)	.	.028	.000	.231	.002	.000	.000	.000	.002	.004	.122
	Compatibility	Correlation Coefficient	.165*	1.000	.280**	.255**	.349**	.235**	.122	.045	.134	-.007	.095
		Sig. (2-tailed)	.028	.	.000	.001	.000	.002	.105	.552	.076	.930	.210
	Observability	Correlation Coefficient	.418**	.280**	1.000	.297**	.368**	.162*	.215**	.267**	.221**	.198**	.126
		Sig. (2-tailed)	.000	.000	.	.000	.000	.031	.004	.000	.003	.008	.096
	Top management support	Correlation Coefficient	.090	.255**	.297**	1.000	.277**	.214**	.280**	.165*	.295**	.217**	.139
		Sig. (2-tailed)	.231	.001	.000	.	.000	.004	.000	.028	.000	.004	.064
	Communication behaviour	Correlation Coefficient	.236**	.349**	.368**	.277**	1.000	.239**	.273**	.120	.162*	.100	.176*
		Sig. (2-tailed)	.002	.000	.000	.000	.	.001	.000	.111	.031	.183	.019
	Organisational readiness	Correlation Coefficient	.283**	.235**	.162*	.214**	.239**	1.000	.249**	.282**	.238**	.238**	.014
		Sig. (2-tailed)	.000	.002	.031	.004	.001	.	.001	.000	.001	.001	.850
	Social motivations	Correlation Coefficient	.308**	.122	.215**	.280**	.273**	.249**	1.000	.503**	.373**	.302**	.092
		Sig. (2-tailed)	.000	.105	.004	.000	.000	.001	.	.000	.000	.000	.224
	Organisational culture	Correlation Coefficient	.382**	.045	.267**	.165*	.120	.282**	.503**	1.000	.336**	.244**	-.043
		Sig. (2-tailed)	.000	.552	.000	.028	.111	.000	.000	.	.000	.001	.567
	Willingness intention	Correlation Coefficient	.230**	.134	.221**	.295**	.162*	.238**	.373**	.336**	1.000	.253**	-.054
		Sig. (2-tailed)	.002	.076	.003	.000	.031	.001	.000	.000	.	.001	.474
	Organisation sz	Correlation Coefficient	.214**	-.007	.198**	.217**	.100	.238**	.302**	.244**	.253**	1.000	.098
		Sig. (2-tailed)	.004	.930	.008	.004	.183	.001	.000	.001	.001	.	.195
	Coercive pressures	Correlation Coefficient	.117	.095	.126	.139	.176*	.014	.092	-.043	-.054	.098	1.000
		Sig. (2-tailed)	.122	.210	.096	.064	.019	.850	.224	.567	.474	.195	.

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

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

Table 7.2 Set of 39 pairs of strong positive relationships among the 11 most influencing factors

Rank	Pair of correlated factors	Correlation value (rs, p)
1	Social motivations ⟺ Organisational culture	(rs= .503, p=.000)
2	Relative advantage ⟺ Observability	(rs= .418, p=.000)
3	Relative advantage ⟺ Organisational culture	(rs= .382, p=.000)
4	Social motivations ⟺ Willingness	(rs= .373, p=.000)
5	Observability ⟺ Communication behaviour	(rs= .368, p=.000)
6	Compatibility ⟺ Communication behaviour	(rs= .349, p=.000)
7	Organisational culture ⟺ Willingness	(rs= .336, p=.000)
8	Organisational culture ⟺ Organisation size	(rs= .336, p=.000)
9	Relative advantage ⟺ Social motivations	(rs= .308, p=.000)
10	Social motivations ⟺ Organisation size	(rs= .302, p=.000)
11	Observability ⟺ Top management support	(rs= .297, p=.000)
12	Top management support ⟺ Willingness	(rs= .295, p=.000)
13	Relative advantage ⟺ Organisational readiness	(rs= .283, p=.000)
14	Organisational readiness ⟺ Willingness	(rs= .282, p=.000)
15	Organisational readiness ⟺ Organisational culture	(rs= .282, p=.000)
16	Compatibility ⟺ Observability	(rs= .280, p=.000)
17	Top management support ⟺ Social motivations	(rs= .280, p=.000)
18	Top management support ⟺ Communication behaviour	(rs= .277, p=.000)
19	Communication behaviour ⟺ Social motivations	(rs= .273, p=.000)
20	Observability ⟺ Organisational culture	(rs= .267, p=.000)
21	Compatibility ⟺ Top management support	(rs= .255, p=.001)
22	Organisational readiness ⟺ Social motivations	(rs= .249, p=.001)
23	Willingness ⟺ Organisation size	(rs= .244, p=.001)
24	Communication behaviour ⟺ Organisational readiness	(rs= .239, p=.001)
25	Organisational readiness ⟺ Organisation size	(rs= .238, p=.001)
26	Relative advantage ⟺ Communication behaviour	(rs= .236, p=.002)
27	Compatibility ⟺ Organisational readiness	(rs= .235, p=.002)
28	Relative advantage ⟺ Willingness	(rs= .230, p=.002)
29	Observability ⟺ Willingness	(rs= .221, p=.003)
30	Top management support ⟺ Organisation size	(rs= .217, p=.004)
31	Observability ⟺ Social motivations	(rs= .215, p=.004)
32	Top management support ⟺ Organisational readiness	(rs= .214, p=.004)
33	Relative advantage ⟺ Organisation size	(rs= .214, p=.004)
34	Observability ⟺ Organisation size	(rs= .198, p=.008)
35	Communication behaviour ⟺ Coercive pressures	(rs= .176, p=.019)
36	Relative advantage ⟺ Compatibility	(rs= .165, p=.028)
37	Top management support ⟺ Organisational culture	(rs= .165, p=.028)
38	Communication behaviour ⟺ Willingness	(rs= .162, p=.031)
39	Observability ⟺ Organisational readiness	(rs= .162, p=.031)

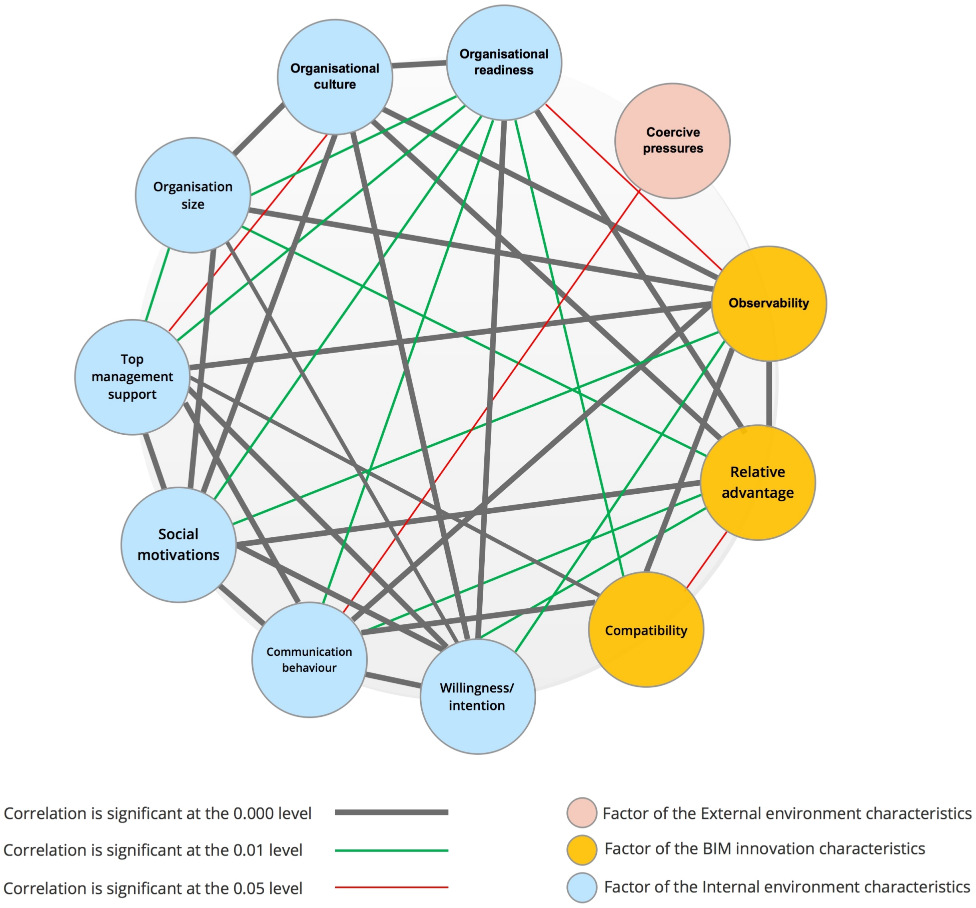


Figure 7.2 The correlations among the 11 most influencing factors on the process of BIM adoption in the form of 39 pairs of strong positive relationships

7.2.2 Correlation among the 11 most influencing factors over the stages of BIM adoption process

In this section, the correlations among the same 11 factors were assessed separately at each stage (i.e., awareness, intention and decision to adopt) using Spearman's rank-order correlation coefficient test while considering the time horizon of the UK Government Construction/BIM Strategy (i.e., pre-announcement of BIM mandate/pre-2011; trial implementation period of BIM mandate/2011-2016; and post-mandate/post-2016).

7.2.2.1 The Awareness Stage

At the '**Awareness**' stage, six factors which were statistically identified (i.e., based on the result of the Logistic Regression Analysis) as the most influencing factors in the process of BIM adoption, namely: *Willingness, Communication behaviour, Observability, Relative advantage, Compatibility,* and *Social motivations*. For the **pre-2011 period**, the two-tailed tests of significance identified six pairs of these factors which indicated that there was a strong positive relationship between each pair. For the **2011-2016 period** at the '**Awareness**' stage, three pairs of these factors which indicated that there was a strong positive relationship between each pair were identified. The results for the **post-2016 period** at the '**Awareness**' stage were excluded as the number of observations was very low (n=2), i.e. two out of the 177 total observations (Table 7.3), (Table 7.6), and (Figure 7.3).

Table 7.3 Correlations among all the influencing factors at the Awareness Stage

				Willingness intention	Communication behaviour	Observability	Relative advantage	Compatibility	Social motivations
Pre-2011	Spearman's rho	Willingness intention	Correlation Coefficient	1.000	-.047	.000	.090	.013	.261**
			Sig. (2-tailed)	.	.635	.996	.357	.895	.007
		Communication behaviour	Correlation Coefficient	-.047	1.000	.246*	.104	.341**	.173
			Sig. (2-tailed)	.635	.	.011	.291	.000	.076
		Observability	Correlation Coefficient	.000	.246*	1.000	.344**	.210*	.137
			Sig. (2-tailed)	.996	.011	.	.000	.031	.161
		Relative advantage	Correlation Coefficient	.090	.104	.344**	1.000	.040	.212*
			Sig. (2-tailed)	.357	.291	.000	.	.682	.029
		Compatibility	Correlation Coefficient	.013	.341**	.210*	.040	1.000	.035
			Sig. (2-tailed)	.895	.000	.031	.682	.	.719
		Social motivations	Correlation Coefficient	.261**	.173	.137	.212*	.035	1.000
			Sig. (2-tailed)	.007	.076	.161	.029	.719	.
2011-2016	Spearman's rho	Willingness intention	Correlation Coefficient	1.000	.097	.176	.137	.069	.255*
			Sig. (2-tailed)	.	.427	.149	.261	.576	.035
		Communication behaviour	Correlation Coefficient	.097	1.000	.183	.154	.139	.089
			Sig. (2-tailed)	.427	.	.132	.207	.255	.469
		Observability	Correlation Coefficient	.176	.183	1.000	.272*	.230	.066
			Sig. (2-tailed)	.149	.132	.	.024	.057	.592
		Relative advantage	Correlation Coefficient	.137	.154	.272*	1.000	.185	.263*
			Sig. (2-tailed)	.261	.207	.024	.	.127	.029
		Compatibility	Correlation Coefficient	.069	.139	.230	.185	1.000	.064
			Sig. (2-tailed)	.576	.255	.057	.127	.	.600
		Social motivations	Correlation Coefficient	.255*	.089	.066	.263*	.064	1.000
			Sig. (2-tailed)	.035	.469	.592	.029	.600	.
Post-2016	Spearman's rho	Willingness intention	Correlation Coefficient	1.000	.	1.000	1.000	-1.000	1.000
			Sig. (2-tailed)	.	.	.	.	.	.
		Communication behaviour	Correlation Coefficient	.	.	.	.	.	.
			Sig. (2-tailed)	.	.	.	.	.	.
		Observability	Correlation Coefficient	.	.	.	.	.	.
			Sig. (2-tailed)	.	.	.	.	.	.
		Relative advantage	Correlation Coefficient	.	.	.	.	.	.
			Sig. (2-tailed)	.	.	.	.	.	.
		Compatibility	Correlation Coefficient	.	.	.	.	.	.
			Sig. (2-tailed)	.	.	.	.	.	.
		Social motivations	Correlation Coefficient	.	.	.	.	.	.
			Sig. (2-tailed)	.	.	.	.	.	.

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

7.2.2.2 The Intention Stage

At the '**Intention/adoption interest**' stage, nine factors which were statistically identified (i.e., based on the result of the Logistic Regression Analysis) as "the most influencing factors in the process of BIM adoption, namely: *Communication behaviour, Relative advantage, Observability, Top management support, Compatibility, Organisation size, Organisational culture, Organisational readiness, and Coercive pressures"* (Ahmed and Kassem, 2018, p.104). For the **pre-2011 period**, the two-tailed tests of significance identified five pairs of these factors which indicated that there was a strong positive relationship between each pair. For the **2011-2016 period** at the '**Intention/adoption interest**' stage, five pairs of these factors which indicated that there was a strong positive relationship between each pair were identified. While the results for the **post-2016 period** at the '**Intention/adoption interest**' stage showed only one strong positive relationship that was between, which was statistically significant (Table 7.4), (Table 7.6), and (Figure 7.3).

Table 7.4 Correlations among all the influencing factors at the Intention/adoption interest Stage

				Communication behaviour	Relative advantage	Observability	Top management support	Compatibility	Organisation size	Organisational culture	Organisational readiness	Coercive pressures
Pre-2011	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	-.158	-.084	.184	.300*	.070	-.260	.336*	.183
			Sig. (2-tailed)	.	.307	.587	.233	.047	.653	.088	.026	.235
		Relative advantage	Correlation Coefficient	-.158	1.000	.133	.064	-.146	.182	.491**	.084	.013
			Sig. (2-tailed)	.307	.	.388	.682	.343	.236	.001	.587	.931
		Observability	Correlation Coefficient	-.084	.133	1.000	.373*	.247	.060	.158	-.062	.124
			Sig. (2-tailed)	.587	.388	.	.013	.106	.700	.307	.691	.421
		Top management support	Correlation Coefficient	.184	.064	.373*	1.000	.162	.286	.156	.173	.334*
			Sig. (2-tailed)	.233	.682	.013	.	.294	.059	.312	.262	.027
		Compatibility	Correlation Coefficient	.300*	-.146	.247	.162	1.000	-.173	-.110	.127	.084
			Sig. (2-tailed)	.047	.343	.106	.294	.	.261	.476	.412	.589
		Organisation size	Correlation Coefficient	.070	.182	.060	.286	-.173	1.000	.125	.180	.000
			Sig. (2-tailed)	.653	.236	.700	.059	.261	.	.418	.242	.998
		Organisational culture	Correlation Coefficient	-.260	.491**	.158	.156	-.110	.125	1.000	.120	-.140
			Sig. (2-tailed)	.088	.001	.307	.312	.476	.418	.	.436	.364
		Organisational readiness	Correlation Coefficient	.336*	.084	-.062	.173	.127	.180	.120	1.000	-.013
			Sig. (2-tailed)	.026	.587	.691	.262	.412	.242	.436	.	.934
		Coercive pressures	Correlation Coefficient	.183	.013	.124	.334*	.084	.000	-.140	-.013	1.000
			Sig. (2-tailed)	.235	.931	.421	.027	.589	.998	.364	.934	.
2011-2016	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	.163	.286**	.099	.211*	-.132	.037	-.010	.080
			Sig. (2-tailed)	.	.072	.001	.278	.019	.145	.686	.914	.381
		Relative advantage	Correlation Coefficient	.163	1.000	.386**	-.162	.104	.087	.274**	.192*	.117
			Sig. (2-tailed)	.072	.	.000	.073	.251	.337	.002	.034	.199
		Observability	Correlation Coefficient	.286**	.386**	1.000	.071	.130	.064	.171	.013	.049
			Sig. (2-tailed)	.001	.000	.	.435	.152	.481	.059	.885	.592
			Correlation Coefficient	.099	-.162	.071	1.000	.097	.041	-.045	.022	.032

		Top management support	Sig. (2-tailed)	.278	.073	.435	.	.287	.653	.623	.810	.724
		Compatibility	Correlation Coefficient	.211*	.104	.130	.097	1.000	-.128	-.100	.086	.084
			Sig. (2-tailed)	.019	.251	.152	.287	.	.158	.272	.343	.353
		Organisation size	Correlation Coefficient	-.132	.087	.064	.041	-.128	1.000	.139	.023	.119
			Sig. (2-tailed)	.145	.337	.481	.653	.158	.	.125	.797	.191
		Organisational culture	Correlation Coefficient	.037	.274**	.171	-.045	-.100	.139	1.000	.169	-.057
			Sig. (2-tailed)	.686	.002	.059	.623	.272	.125	.	.062	.533
		Organisational readiness	Correlation Coefficient	-.010	.192*	.013	.022	.086	.023	.169	1.000	-.018
			Sig. (2-tailed)	.914	.034	.885	.810	.343	.797	.062	.	.846
		Coercive pressures	Correlation Coefficient	.080	.117	.049	.032	.084	.119	-.057	-.018	1.000
			Sig. (2-tailed)	.381	.199	.592	.724	.353	.191	.533	.846	.
Post-2016	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	.627	.338	.041	.105	.166	-.299	-.063	.120
			Sig. (2-tailed)	.	.052	.339	.910	.772	.647	.401	.862	.740
		Relative advantage	Correlation Coefficient	.627	1.000	.400	-.067	.305	-.235	-.282	.388	.315
			Sig. (2-tailed)	.052	.	.252	.854	.392	.514	.430	.269	.375
		Observability	Correlation Coefficient	.338	.400	1.000	.546	.155	-.196	-.188	-.432	.261
			Sig. (2-tailed)	.339	.252	.	.103	.669	.587	.603	.212	.467
		Top management support	Correlation Coefficient	.041	-.067	.546	1.000	.180	.022	-.177	-.259	.359
			Sig. (2-tailed)	.910	.854	.103	.	.618	.952	.624	.470	.309
		Compatibility	Correlation Coefficient	.105	.305	.155	.180	1.000	-.179	.380	.186	.911**
			Sig. (2-tailed)	.772	.392	.669	.618	.	.620	.279	.607	.000
		Organisation size	Correlation Coefficient	.166	-.235	-.196	.022	-.179	1.000	-.546	.007	-.047
			Sig. (2-tailed)	.647	.514	.587	.952	.620	.	.103	.985	.898
		Organisational culture	Correlation Coefficient	-.299	-.282	-.188	-.177	.380	-.546	1.000	-.198	.149
			Sig. (2-tailed)	.401	.430	.603	.624	.279	.103	.	.583	.681
		Organisational readiness	Correlation Coefficient	-.063	.388	-.432	-.259	.186	.007	-.198	1.000	.338
			Sig. (2-tailed)	.862	.269	.212	.470	.607	.985	.583	.	.340
		Coercive pressures	Correlation Coefficient	.120	.315	.261	.359	.911**	-.047	.149	.338	1.000
			Sig. (2-tailed)	.740	.375	.467	.309	.000	.898	.681	.340	.

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

7.2.2.3 The Decision Stage

At the '**Decision**' stage, seven factors which were statistically identified (i.e., based on the result of the Logistic Regression Analysis) as "the most influencing factors in the process of BIM adoption, namely: *Communication behaviour, Organisation size, Relative advantage, Compatibility, Coercive pressures, Organisational readiness* and *Top management support*" (Ahmed and Kassem, 2018, p.104). For the **pre-2011 period**, the two-tailed tests of significance identified one pair of these factors which indicated that there was a strong negative relationship, and two pairs with a strong positive relationship between each pair. For the **2011-2016 period** at the '**Decision**' stage, the two-tailed tests of significance identified one pair of these factors which indicated that there was a strong negative relationship and three pairs with a strong positive relationship between each pair which was statistically significant. For the **post-2016 period** at the '**Decision**' stage, the two-tailed tests of significance identified three pairs of these factors which indicated that there was a strong positive relationship and one pair with a strong negative relationship, which was statistically significant (Table 7.5), (Table 7.6), and (Figure 7.3).

Table 7.5 Correlations among all the influencing factors at the Decision Stage

				Communication behaviour	Organisation size	Relative advantage	Compatibility	Coercive pressures	Organisational readiness	Top management support
Pre-2011 period	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	-.054	-.424*	.155	-.071	.367*	-.106
			Sig. (2-tailed)	.	.773	.017	.406	.703	.043	.572
		Organisation size	Correlation Coefficient	-.054	1.000	.127	-.160	.017	-.024	.129
			Sig. (2-tailed)	.773	.	.496	.389	.926	.898	.490
		Relative advantage	Correlation Coefficient	-.424*	.127	1.000	-.237	-.041	-.173	-.202
			Sig. (2-tailed)	.017	.496	.	.198	.828	.351	.277
		Compatibility	Correlation Coefficient	.155	-.160	-.237	1.000	-.084	.058	.026
			Sig. (2-tailed)	.406	.389	.198	.	.654	.755	.891
		Coercive pressures	Correlation Coefficient	-.071	.017	-.041	-.084	1.000	-.062	.375*
			Sig. (2-tailed)	.703	.926	.828	.654	.	.740	.038
		Organisational readiness	Correlation Coefficient	.367*	-.024	-.173	.058	-.062	1.000	-.134
			Sig. (2-tailed)	.043	.898	.351	.755	.740	.	.472
		Top management support	Correlation Coefficient	-.106	.129	-.202	.026	.375*	-.134	1.000
			Sig. (2-tailed)	.572	.490	.277	.891	.038	.472	.
2011-2016 period	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	-.189*	.243*	.302**	.158	-.028	.118
			Sig. (2-tailed)	.	.049	.011	.001	.102	.777	.220
		Organisation size	Correlation Coefficient	-.189*	1.000	.186	-.143	.079	.126	.026
			Sig. (2-tailed)	.049	.	.052	.138	.412	.192	.785
		Relative advantage	Correlation Coefficient	.243*	.186	1.000	.066	.133	.210*	-.031
			Sig. (2-tailed)	.011	.052	.	.493	.170	.029	.749
		Compatibility	Correlation Coefficient	.302**	-.143	.066	1.000	.100	.054	.077
			Sig. (2-tailed)	.001	.138	.493	.	.302	.578	.427
		Coercive pressures	Correlation Coefficient	.158	.079	.133	.100	1.000	-.015	.035
			Sig. (2-tailed)	.102	.412	.170	.302	.	.873	.715
		Organisational readiness	Correlation Coefficient	-.028	.126	.210*	.054	-.015	1.000	.066
			Sig. (2-tailed)	.777	.192	.029	.578	.873	.	.497
		Top management support	Correlation Coefficient	.118	.026	-.031	.077	.035	.066	1.000
			Sig. (2-tailed)	.220	.785	.749	.427	.715	.497	.
Post-2016 period	Spearman's rho	Communication behaviour	Correlation Coefficient	1.000	.127	.010	-.139	-.141	.014	.182
			Sig. (2-tailed)	.	.454	.955	.413	.405	.933	.282
		Organisation size	Correlation Coefficient	.127	1.000	-.078	-.138	-.199	.032	.301
			Sig. (2-tailed)	.454	.	.647	.415	.237	.852	.071
		Relative advantage	Correlation Coefficient	.010	-.078	1.000	.348*	-.101	.414*	.087
			Sig. (2-tailed)	.955	.647	.	.035	.550	.011	.607
		Compatibility	Correlation Coefficient	-.139	-.138	.348*	1.000	-.057	.313	.355*
			Sig. (2-tailed)	.413	.415	.035	.	.739	.059	.031
		Coercive pressures	Correlation Coefficient	-.141	-.199	-.101	-.057	1.000	-.352*	-.130
			Sig. (2-tailed)	.405	.237	.550	.739	.	.033	.443
		Organisational readiness	Correlation Coefficient	.014	.032	.414*	.313	-.352*	1.000	.146
			Sig. (2-tailed)	.933	.852	.011	.059	.033	.	.389
		Top management support	Correlation Coefficient	.182	.301	.087	.355*	-.130	.146	1.000
			Sig. (2-tailed)	.282	.071	.607	.031	.443	.389	.

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 7.6 The correlations among the 11 most influencing factors (31 pairs of strong relationships) on the BIM adoption process stages (time-dependent)

Stage	Time horizon	Pair of correlated factors	Correlation value
Awareness	Pre-2011	Observability ⟺ Relative advantage	(rs= .344, p=.000)
		Communication behaviour ⟺ Compatibility	(rs= .341, p=.000)
		Social motivations ⟺ Willingness	(rs= .261, p=.007)
		Communication behaviour ⟺ Observability	(rs= .246, p=.011)
		Relative advantage ⟺ Social motivations	(rs= .212, p=.029)
		Observability ⟺ Compatibility	(rs= .210, p=.031)
	2011-2016	Observability ⟺ Relative advantage	(rs= .272, p=.024)
		Relative advantage ⟺ Social motivations	(rs= .263, p=.029)
		Social motivations ⟺ Willingness	(rs= .255, p=.035)
	Post-2016	Excluded /inadequate statistically	N/A
Intention	Pre-2011	Organisational culture ⟺ Relative advantage	(rs= .491, p=.001)
		Observability ⟺ Top management support	(rs= .373, p=.013)
		Communication behaviour ⟺ Organisational readiness	(rs= .336, p=.026)
		Top management support ⟺ Coercive pressures	(rs= .334, p=.027)
		Communication behaviour ⟺ Compatibility	(rs= .300, p=.047)
	2011-2016	Observability ⟺ Relative advantage	(rs= .386, p=.000)
		Communication behaviour ⟺ Observability	(rs= .286, p=.001)
		Organisational culture ⟺ Relative advantage	(rs= .274, p=.002)
		Communication behaviour ⟺ Compatibility	(rs= .211, p=.019)
		Relative advantage ⟺ Organisational readiness	(rs= .192, p=.034)
	Post-2016	Compatibility ⟺ Coercive pressures	(rs= .911, p=.000)
Decision	Pre-2011	Communication behaviour ⟺ Relative advantage	(rs= -.424, p=.017)
		Coercive pressures ⟺ Top management support	(rs= .375, p=.038)
		Communication behaviour ⟺ Organisational readiness	(rs= .367, p=.043)
	2011-2016	Communication behaviour ⟺ Organisation size	(rs= -.189, p=.049)
		Communication behaviour ⟺ Compatibility	(rs= .302, p=.001)
		Communication behaviour ⟺ Relative advantage	(rs= .243, p=.011)
		Relative advantage ⟺ Organisational readiness	(rs= .210, p=.029)
	Post-2016	Relative advantage ⟺ Organisational readiness	(rs= .414, p=.011)
		Compatibility ⟺ Top management support	(rs= .355, p=.031)
		Relative advantage ⟺ Compatibility	(rs= .348, p=.035)
		Coercive pressures ⟺ Organisational readiness	(rs= -.352, p=.033)

⟺ strong positive relationship ⟺ strong negative relationship

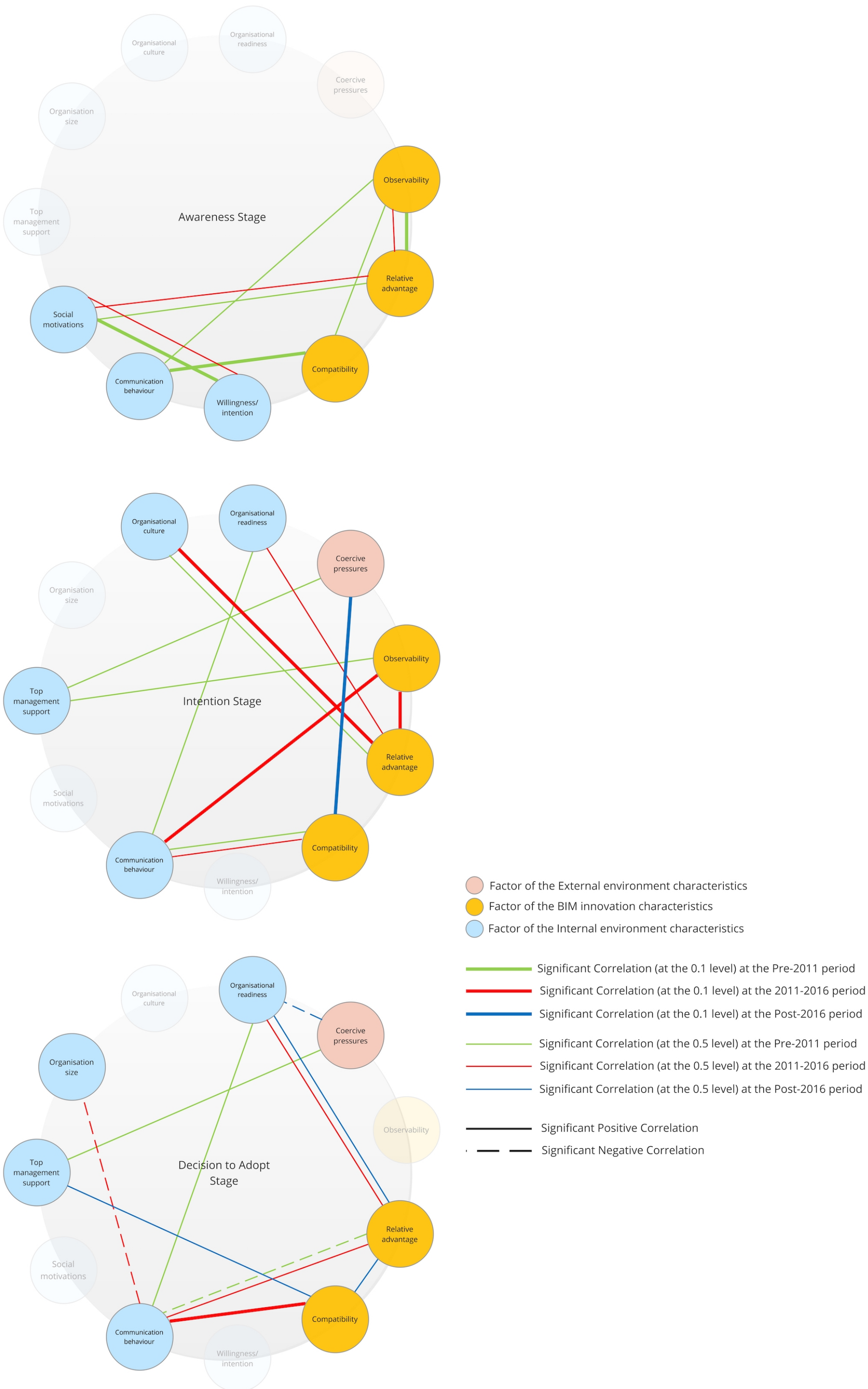


Figure 7.3 The correlations among the 11 most influencing factors on the BIM adoption process stages while considering the time horizon in the form of 31 pairs of strong relationships

7.3 Findings and discussion of the Correlation Analysis among the 11 most influencing factors on the stages of BIM adoption process

Understanding "the "impact of drivers on BIM adoption entails the assessment and comparison of the relative effect of key market-wide drivers such as BIM mandates (e.g. the UK BIM mandate), other institutional pressures, BIM innovation characteristics, and organisational characteristics, on the decision to adopt BIM by organisations" (Ahmed and Kassem, 2018, p.104). The following sections will demonstrate and discuss the results of the correlation analysis among the 11 most influencing factors. The findings will inform developing the Two-dimensional characterisation model of BIM adoption (in this Chapter) and developing the Systems Thinking Models (in the next Chapter):

- (**Observability ⟺ Relative advantage**): this strong positive relationship suggests that as the anticipated benefits or perceived profits that the innovation provides to an organisation (i.e., based on the revealed advantages of BIM to existing adopters) become more obvious and visible to the potential adopters, these potential adopters start realising the relative advantage of BIM. This pair of factors (i.e., Observability ⟺ Relative advantage) has an extended influence by transferring its effect (a) across two consecutive time-horizons of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Awareness'); and (b) across two consecutive stages within the same time-horizon (i.e., from 'Awareness' to 'Intention' in 2011-2016) (Figure 7.5, Figure 7.4, and Figure 7.7). Hence, this correlation may (1) prompt the organisations' *awareness* to gain more knowledge about the innovation; and (2) encourage more organisations to formulate and develop a favourable attitude (i.e., Intention) towards BIM adoption.
- (**Communication behaviour ⟺ Compatibility**): this strong positive relationship proposes that as an architectural organisation (i.e., potential adopter) increases its communication channels and network of connections (i.e., informal/ inter-organisational communication through interpersonal channels), the more the perceived compatibility of BIM with existing processes

in this practice increases. In addition, this pair of factors (i.e., Communication behaviour ⟺ Compatibility) has a continuous influence/relationship by transferring its effect (a) across three consecutive stages within two time-horizons (i.e., from 'Awareness' to 'Intention' in Pre-2011, then from 'Intention' to 'Decision' in 2011-2016) and (b) across two consecutive periodical time-horizon of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Intention') (Figure 7.5, Figure 7.7, and Figure 7.11). Thus, this correlation may (1) prompt the organisations' *awareness* to gain more knowledge about the innovation (i.e., BIM); (2) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (3) enable the architectural organisation (i.e., potential adopter) to develop and make the decision to adopt BIM.

- (**Social motivations ⟺ Willingness**): this strong positive relationship suggests that the more organisation's members are motivated to engage in behaviours that benefit others (e.g., stimulating knowledge exchange, and focusing on collective goals), the more they would be willing (i.e., behavioural willingness and intention) to adopt BIM. This pair of factors (i.e., Social motivations ⟺ Willingness) has an extended influence by transferring its effect across two consecutive time-horizons of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Awareness') (Figure 7.5 and Figure 7.4). Hence, social motivations can be seen as a catalyst factor that triggers the organisations' *Willingness* to gain more knowledge (i.e., raises the awareness) about BIM.
- (**Communication behaviour ⟺ Observability**): this strong positive relationship proposes that as an architectural organisation increases its communication channels and network of connections (i.e., informal/ inter-organisational communication through interpersonal channels), the more visible and tangible become the results of successful BIM adoption examples of other organisations. This pair of factors (i.e., Communication behaviour ⟺ Observability) has a continuous influence/relationship across two consecutive stages within two time-horizons (i.e., from Pre-2011 at 'Awareness' to 2011-2016 at 'Intention') (Figure 7.5 and Figure 7.7). Therefore, this correlation may

(1) motivate the organisations' awareness to gain more knowledge about BIM; and (2) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption.

- (**Social motivations ⟺ Relative advantage**): this strong positive relationship suggests that the more the organisation's members are motivated to engage in behaviours that benefit others (e.g., stimulating knowledge exchange, and focusing on collective goals), the more the perceived benefits obtained from adopting BIM increase. Hence, this may prompt organisations' *awareness* to gain more knowledge about the innovation BIM. In addition, this pair of factors has an extended influence by transferring its effect across two consecutive time-horizons of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Awareness') (Figure 7.5 and Figure 7.4).
- (**Observability ⟺ Compatibility**): this strong positive relationship suggests that the more visible and tangible results of successful BIM adoption examples of other organisations increase, the more that clarifying how BIM can be aligned with the potential adopter's previous experiences and current needs and values increases. Thus, this may trigger the organisations' *awareness* to gain more knowledge about BIM. This pair of correlation can be recognised in the Pre-2011 period at the 'Awareness' stage. (Figure 7.5).
- (**Organisational culture ⟺ Relative advantage**): this strong positive relationship suggests that as the shared norms, beliefs, and traditions held by the members of an organisational practice increase, the more the perceived benefits obtained from adopting BIM increase. Thus, this may formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption. Also, this pair of factors has a continuous influence/relationship by migrating its effect across two consecutive time-horizons of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Intention') (Figure 7.6 and Figure 7.7).
- (**Observability ⟺ Top management support**): this strong positive relationship suggests that the more visible and tangible results of successful BIM adoption examples of other organisations, the more support from executives in the architectural organisations become available. Therefore, this

may encourage the general attitude of formulating a favourable attitude (i.e., Intention) towards BIM adoption. This pair of correlation can be recognised in the Pre-2011period at the 'Intention' stage. (Figure 7.6).

- (**Communication behaviour ⟺ Organisational readiness**): this strong positive relationship proposes that as an architectural organisation increases its communication channels and the network of connections (i.e., informal/ inter-organisational communication through interpersonal channels), the more the organisation engages in active preparation to adopt and implement BIM. Also, this pair of factors has an extended influence by transferring its effect across two consecutive stages within the same time-horizon (i.e., from 'Intention' to 'Decision' in Pre-2011) (Figure 7.6 and Figure 7.9). Therefore, this correlation may (1) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (2) enable the architectural organisation (i.e., potential adopter) to develop and make the decision to adopt BIM.
- (**Coercive pressures ⟺ Top management support**): this strong positive relationship suggests that the presence of formal and informal mandates (e.g., enforcing policies and standards by powerful partners, clients, and government pressures) on the potential adopters, will drive executives support in architectural organisations to support BIM adoption. In addition, this pair of factors has an extended influence by transferring its effect across two consecutive stages within the same time-horizon (i.e., from 'Intention' to 'Decision' in Pre-2011) (Figure 7.6 and Figure 7.9). Therefore, this correlation may (1) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (2) enable the architectural organisation (i.e., potential adopter) to develop and make the decision to adopt BIM.
- (**Organisational readiness ⟺ Relative advantage**): this strong positive relationship proposes that the more the organisation members collaborate to increase the preparation to adopt and implement BIM and their mutual determination to perform the change, the more the perceived benefits obtained

from adopting BIM increase. This pair of factors has an extended influence by transferring its effect (1) across two consecutive stages within the same periodical time-horizon (i.e., from 'Intention' to 'Decision' in 2011-2016) and (2) across two consecutive time-horizons of the same stage (i.e., from 2011-2016 to post-2016 at 'Decision') (Figure 7.7, Figure 7.11, and Figure 7.10). Thus, this correlation may (1) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (2) enable the architectural organisation (i.e., potential adopter) to develop and make the decision to adopt BIM.

- (**Coercive pressures ⇔ Compatibility**): this strong positive relationship suggests that the presence of formal and informal mandates (e.g., enforcing policies and standards by powerful partners, clients, and government pressures) increases the perception of BIM compatibility by potential adopters who perceive BIM as aligned with their previous experience and current and future needs and value.. Therefore, this may encourage the general attitude of formulating a favourable attitude (i.e., Intention) towards BIM adoption. This pair of correlation can be recognised in the Post-2016 period at the 'Intention' stage Figure 7.8.
- (**Relative advantage ⇔ Communication behaviour**): this pair of factors has shown two opposite interplays: a strong negative relationship and a strong positive relationship across two consecutive time-horizons of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Decision') (Figure 7.9 and Figure 7.11). The strong negative relationship suggests that the lower the perceived benefits obtained from adopting BIM are, the more openness and engagement of the potential adopters with social groupings and networks interested in BIM adoption and promotion becomes. This may be due to the fact that the relatively low cumulative percentage (17.5% based on the result) of the earliest BIM adopters - who made the decision to adopt BIM in the *Pre-2011 period at the 'Decision' stage* – were reluctant to reveal and share what may be considered as a competitive advantage to potential adopters who were still hesitant to adopt BIM. Thus, this drives the potential adopters to proactively

increase their communication behaviours to ensure the acquisition of and embracing BIM technologies and to secure their existence in a social network. Whereas, the strong positive relationship indicates that as the architectural organisation increase the openness and engagement with social groupings and networks interested in BIM adoption and promotion, the more the perceived benefits obtained from adopting BIM increase. This contrary result may be due to the relatively highest cumulative percentage (79%) of the BIM majority existing adopters in the trial implementation period of BIM mandate/2011-2016 (i.e., comparing to 17.5% in the Pre-2011 period) who became willing to reveal advantages of BIM which encouraged the hesitant/potential adopters through their communication behaviours.

- (**Organisation size ⟺ Communication behaviour**): this strong negative relationship proposes that smaller architectural organisations are more likely seeking to increase their communication channels and network of connections (i.e., informal/ inter-organisational communication through interpersonal channels). Thus, this may enable an architectural organisation to develop and make the decision to adopt BIM. This pair of correlation can be recognised in the 2011-2016 period at the 'Decision' stage (Figure 7.11).
- (**Compatibility ⟺ Top management support**): this strong positive relationship indicates that as the perceived compatibility of BIM with existing processes increases, more executive support in the architectural organisations become available to develop and make the decision to adopt BIM. This pair of correlation can be recognised in the Post-2016 period at the 'Decision' stage (Figure 7.10).
- (**Relative advantage ⟺ Compatibility**): this strong positive relationship suggests that the more the perceived benefits obtained from adopting BIM increase, the higher the perception of BIM compatibility is within architectural organisations. Hence, this may enable the architectural organisation (i.e., potential adopter) to develop and make the decision to adopt BIM. This pair of correlation can be recognised in the Post-2016 period at the 'Decision' stage (Figure 7.10).

- (**Coercive pressures ⟺ Organisational readiness**): this strong negative relationship proposes that the availability of formal and informal mandates (e.g., enforcing policies and standards by powerful partners, clients, and government pressures) on the potential adopters, may have a detrimental effect on organisational readiness. A possible explanation for this contradictory result is the following: at the time the BIM mandate has taken place (i.e., Post-2016) the majority of organisations (96.5%) have made their decision to adopt BIM. The residue of adopters/laggards (i.e., 3.5% based on the results) who were left behind became more vulnerable to external/coercive pressures. Thus, those laggards have also made the decision to adopt BIM due to the time limitation and the influence of these external pressures (i.e., the BIM mandate) rather than the result of an achieved organisational readiness. (Figure 7.10).

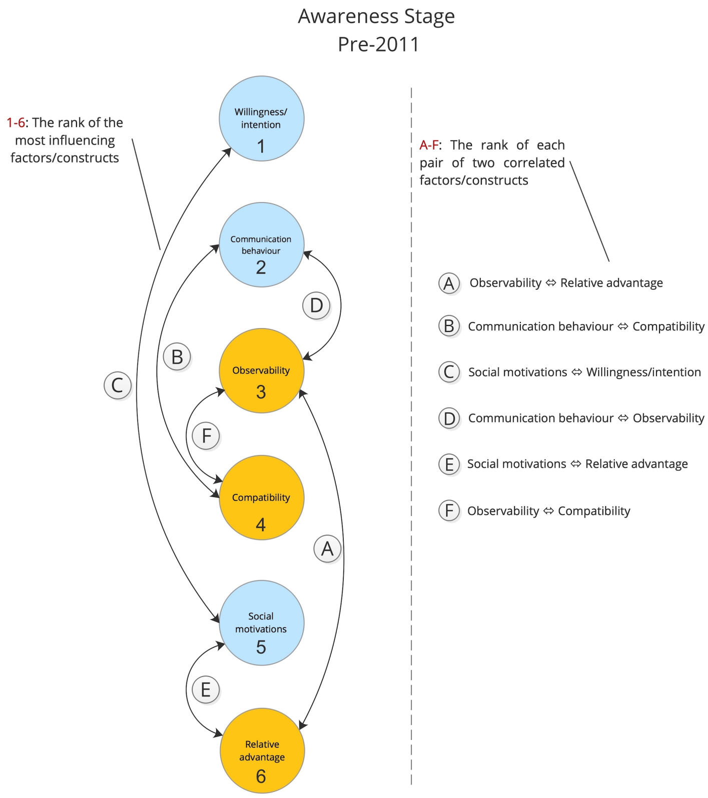


Figure 7.5 The correlations among the most influencing factors on the BIM adoption process for the Pre-2011 period at the 'Awareness' stage in the form of six pairs of strong relationships

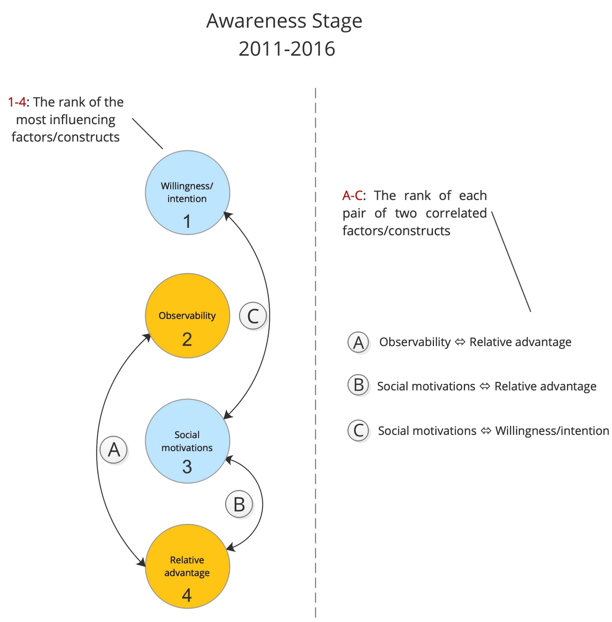


Figure 7.4 The correlations among the most influencing factors on the BIM adoption process for the 2011-2016 period at the 'Awareness' stage in the form of three pairs of strong relationships

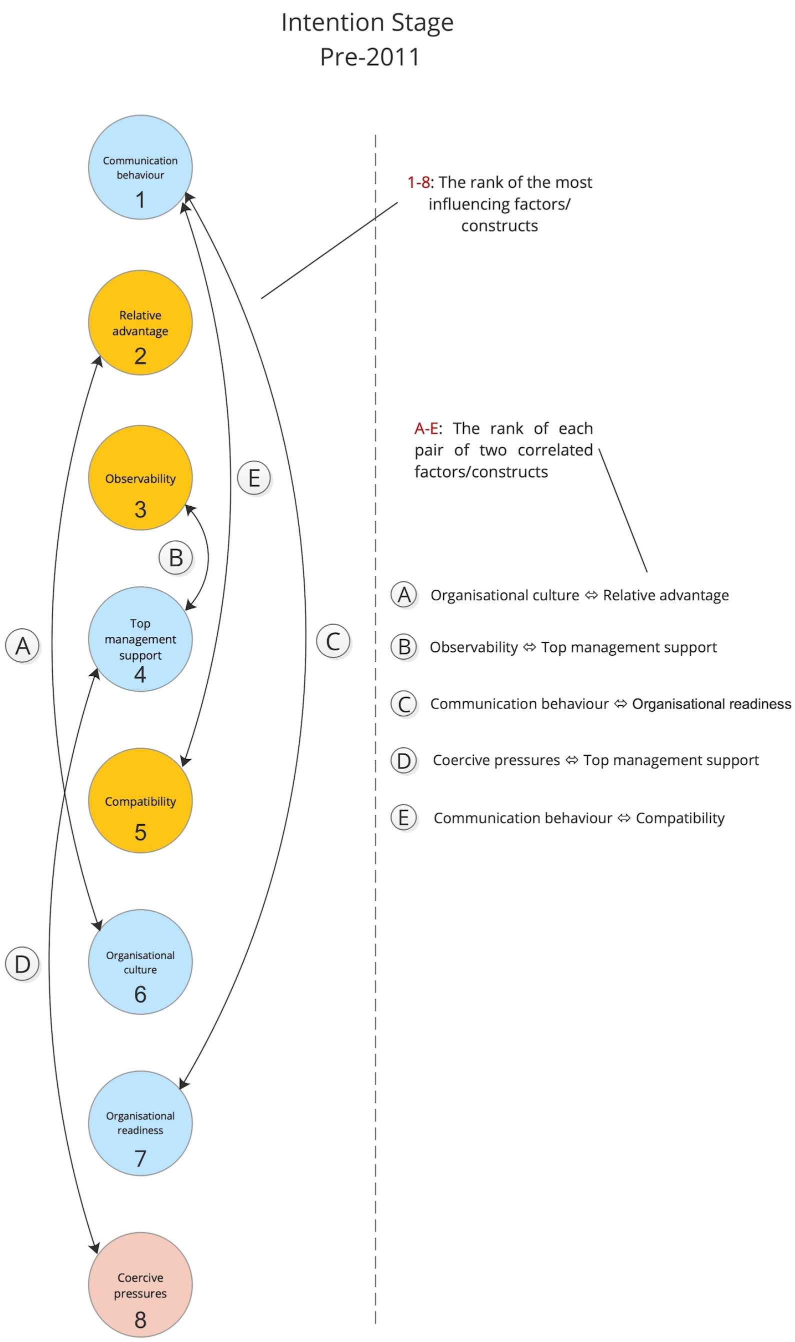


Figure 7.6 The correlations among the most influencing factors on the BIM adoption process for the Pre-2011 period at the 'Intention' stage in the form of five pairs of strong relationships

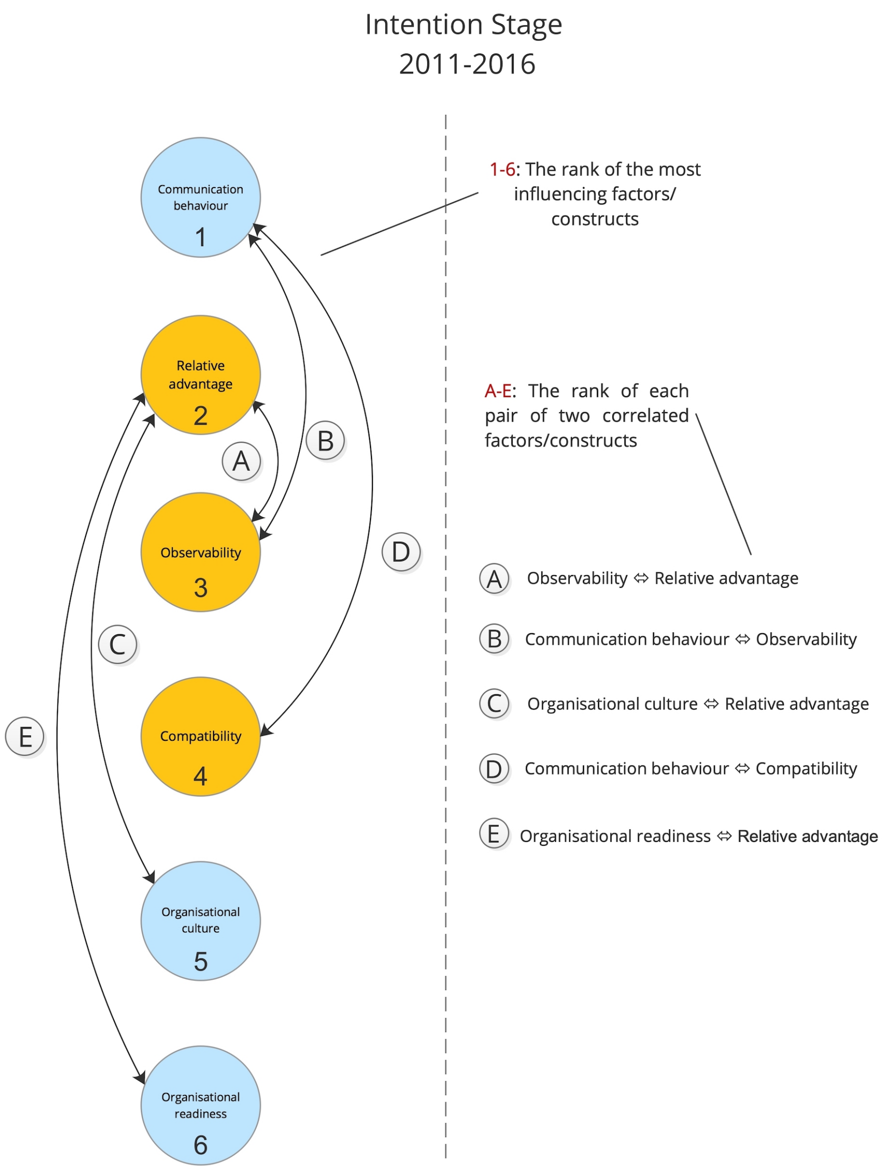


Figure 7.7 The correlations among the most influencing factors on the BIM adoption process for the 2011-2016 period at the 'Intention' stage in the form of five pairs of strong relationships

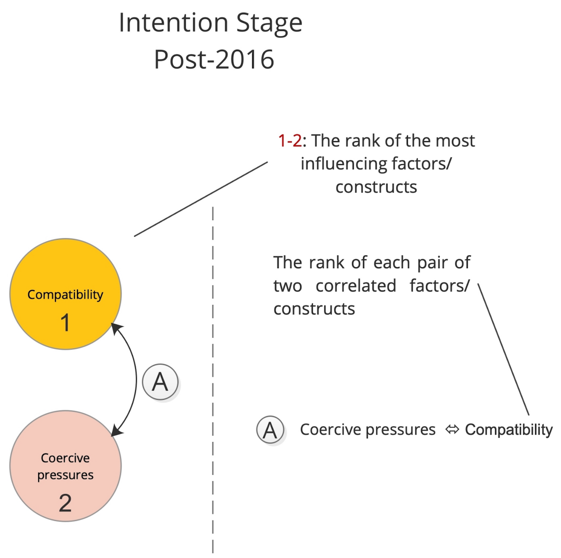


Figure 7.8 The correlations among the most influencing factors on the BIM adoption process for the Post-2016 period at the 'Intention' stage in the form of one pair of strong relationships

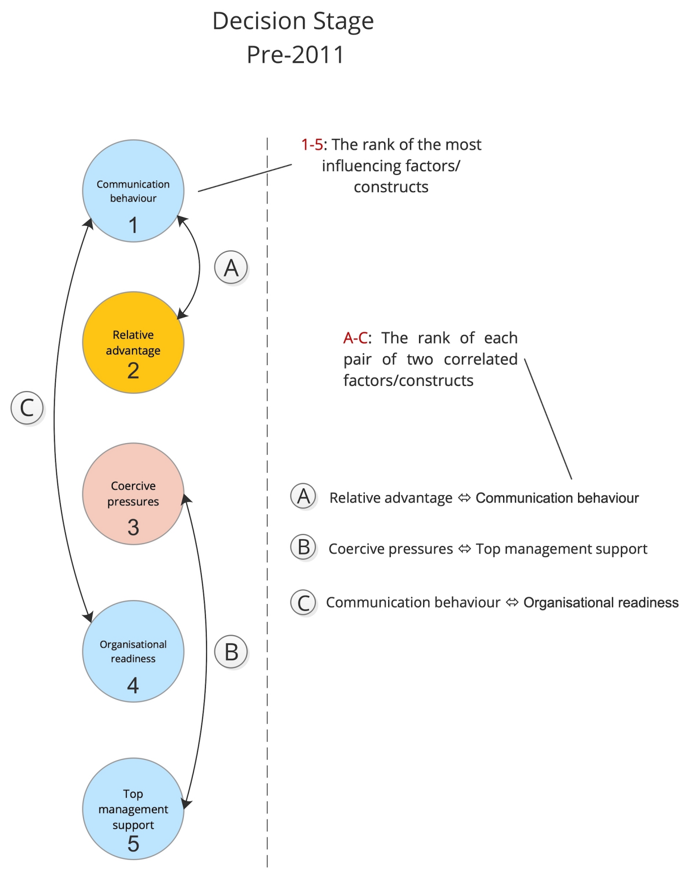


Figure 7.9 The correlations among the most influencing factors on the BIM adoption process for the Pre-2011 period at the 'Decision' stage in the form of three pairs of strong relationships

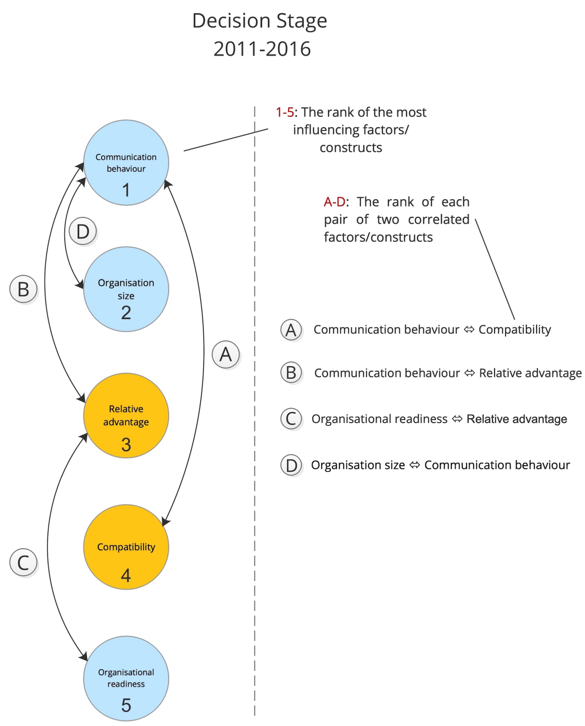


Figure 7.11 The correlations among the most influencing factors on the BIM adoption process for the 2011-2016 period at the 'Decision' stage in the form of four pairs of strong relationships

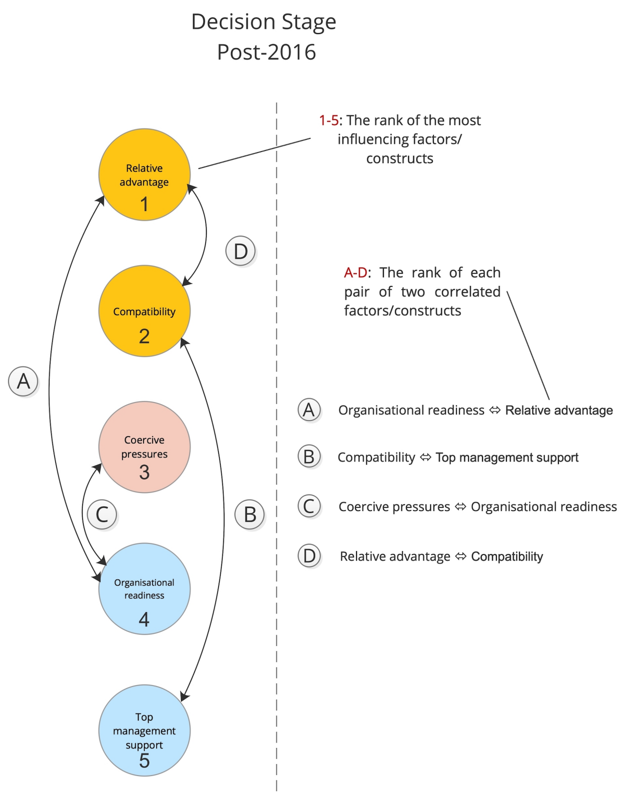


Figure 7.10 The correlations among the most influencing factors on the BIM adoption process for the Post-2016 period at the 'Decision' stage in the form of four pairs of strong relationships

7.4 Developing a Two-dimensional Characterisation Model of the BIM adoption process for the UK Architectural Organisations

Having identified the 11 most influencing factors - based on the Ordinal Logistic Regression Analysis results - on the three stages of BIM adoption process, and given the results from the correlation statistical analysis among these identified factors, a Two-dimensional Characterisation Model for the BIM adoption process can be developed using knowledge synthesis as shown in the following steps:

Step 1: The 11 top influencing factors were identified from the testing of the study's hypotheses using the Ordinal Logistic Regression Analysis. These factors were assigned to the stages on which they exert influence (i.e., awareness, intention, and decision) as shown in Figure 6.2 (in Chapter 6);

Step 2: The second cycle of correlations analysis among the 11 factors (Section 7.2.2) resulted in a set of 31 pairs of strong relationships (28 strong positive relationships and 3 negative ones) and considered the time horizon of the UK BIM initiative. These correlations show how the factors' interplay exerts influence on particular stages of the BIM adoption process (As summarised in Table 7.6 and depicted in Figure 7.3).

These results are visualised in Figure 7.12 using a two-dimensional model, with one dimension being the stages of the BIM adoption process and the other dimension being the time-horizon, with the following conventions:

- The pairs of factors influencing awareness were top-to-bottom (A to F) arranged according to their actual power of influence. For example, in Figure 7.12 the first block of the 'Awareness stage' in the Pre-2011 period ranks the following pairs from top-to-bottom in a descending order: [i.e. *Observability* ⟺ *Relative advantage* (*rs*= .344, *p*=.000); *Communication behaviour* ⟺ *Compatibility* (*rs*= .341, *p*=.000); *Social motivations* ⟺ *Willingness* (*rs*= .261, *p*=.007); *Communication behaviour* ⟺ *Observability* (*rs*= .246, *p*=.011); *Social motivations* ⟺ *Relative advantage* (*rs*= .212, *p*=.029); and *Observability* ⟺ *Compatibility* (*rs*= .210, *p*=.031)].

- The level of influence of each pair is symbolised using simple pie diagrams: 1 full circle for p-values between p=0.000 – p=0.009; ¾ circle for p-values between p=0.01 – p=0.025; ½ circle for p-values between p=0.026 – p=0.04; and ¼ circle for p-values between p=0.041 – p=0.05.

Three colour codes are used to identify the factors appurtenance to the three driver clusters. Pink, orange, and blue are used for the External Environment Characteristics, Innovation/BIM Characteristics, and Organisation's Internal Environment Characteristics, respectively.

The profiling of micro BIM adoption with the model (Figure 7.12) presents an integrated view of the adoption problem by addressing the interactions between: pairs of correlated adoption factors, stages of the BIM adoption process, and the time horizon. The model shows that micro BIM adoption is characterised by a dynamic behaviour where:

- Correlated pairs of factors exert a varying level of influence within each adoption stage and across different stages and time horizons. For example, the pair "*Communication behaviour ⇔ Compatibility*" has a continuous influence with its effect transferring (a) across three consecutive stages within two periodical time-horizon (i.e., from 'Awareness' to 'Intention' in Pre-2011, then from 'Intention' to 'Decision' in 2011-2016), and (b) across two consecutive periodical time-horizon of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Intention'). Hence, this pair plays a role in driving the organisation to gain knowledge about the innovation (i.e. formulate awareness); develop a favourable attitude (i.e., Intention) towards BIM adoption; and move towards formulating the decision to adopt BIM;
- Factors involved in each correlated pair influence BIM adoption generally change across the adoption stages and the time horizon. For example, the pairs (*Relative advantage ⇔ Observability*), (*Communication behaviour ⇔ Compatibility*), and (*Relative advantage ⇔ Organisational readiness*) all change the composition of the pair involved in exerting influence on the BIM adoption process; and

- Pairs of factors influencing adoption stages over time often combine constructs from the three clusters of drivers (i.e., Innovation/BIM Characteristics, External Environment Characteristics, and Organisation's Internal Environment Characteristics). This indicates that micro BIM adoption is a dynamics system whose understanding requires the simultaneous contemplation of these three environments.

According to the general survey results of this study (i.e., in Chapter 4) regarding the average year of occurrence for each stage of the BIM adoption process (i.e., Awareness, Intention, and Decision) considering the three-time horizons, ten possible patterns can be recognised including the most representative scenario for the UK architecture sector (Table 7.7). Pattern **4** represents the UK most common scenario of the BIM adoption process with a percentage of 27% of the total sample, and the year average occurrence of the Awareness Stage is 2010 (i.e., Pre-2011 Period), the Intention Stage is 2012 (i.e., 2011-2016 Period), and the Decision Stage is 2013 (i.e., 2011-2016 Period). In addition to this pattern, two patterns **7** (25%) and **1**(18%) represent the three common patterns in the UK architectural sector. The others (i.e., patterns 2, 3, 5, 6, 8, 9, and 10) represent also possible adoption patterns but hey are less common than the former ones.

These findings, by revealing the different types of interactions between the factors affecting the BIM adoption process across two important dimensions (i.e., stages of the BIM adoption process stages, and time) improve the understanding of the micro BIM adoption. And by so doing, it could inform micro BIM adoption implementation plans. For example, in the case of Pair B (i.e., communication behaviour ⇔ compatibility) influencing the awareness stage at pre-2011, a decision maker may implement activities that change the communication behaviour (i.e., the degree of openness and engagement of an organisation with social groupings and networks interested in innovation adoption and promotion) of an organisation to make the organisation perceives the innovation as more compatible with their previous experiences and current needs and values. Further, in organisations where readiness was achieved between [2011 - 2016], other pairs of correlated factors are involved, and none of these pairs entails factors from Pair B (communication behaviour ⇔

compatibility). By interpreting the model's results in this way, decision makers may be able to calibrate and tailor micro BIM adoption activities to their special circumstances depending on their position across both the adoption and time dimensions. Moreover, further commonalities and differences can be recognised by comparing two patterns and their pertinent stages and time horizons (Figure 7.12).

Table 7.7 The Ten possible Patterns of year average of occurrence for each stage of the BIM adoption process

Pattern No	Stages	Pre-2011 Period	2011-2016 Period	Post-2016 Period	Percentage
1	Awareness	→			
	Intention	→			18%
	Decision	→			
2	Awareness	→			
	Intention	→			7%
	Decision		→		
3	Awareness	→			
	Intention	→			1%
	Decision			→	
4	Awareness	→			
	Intention		→		27%
	Decision		→		
5	Awareness	→			
	Intention		→		7%
	Decision			→	
6	Awareness	→			
	Intention			→	1%
	Decision			→	
7	Awareness		→		
	Intention		→		25%
	Decision		→		
8	Awareness		→		
	Intention		→		10%
	Decision			→	
9	Awareness		→		
	Intention			→	3%
	Decision			→	
10	Awareness			→	
	Intention			→	1%
	Decision			→	

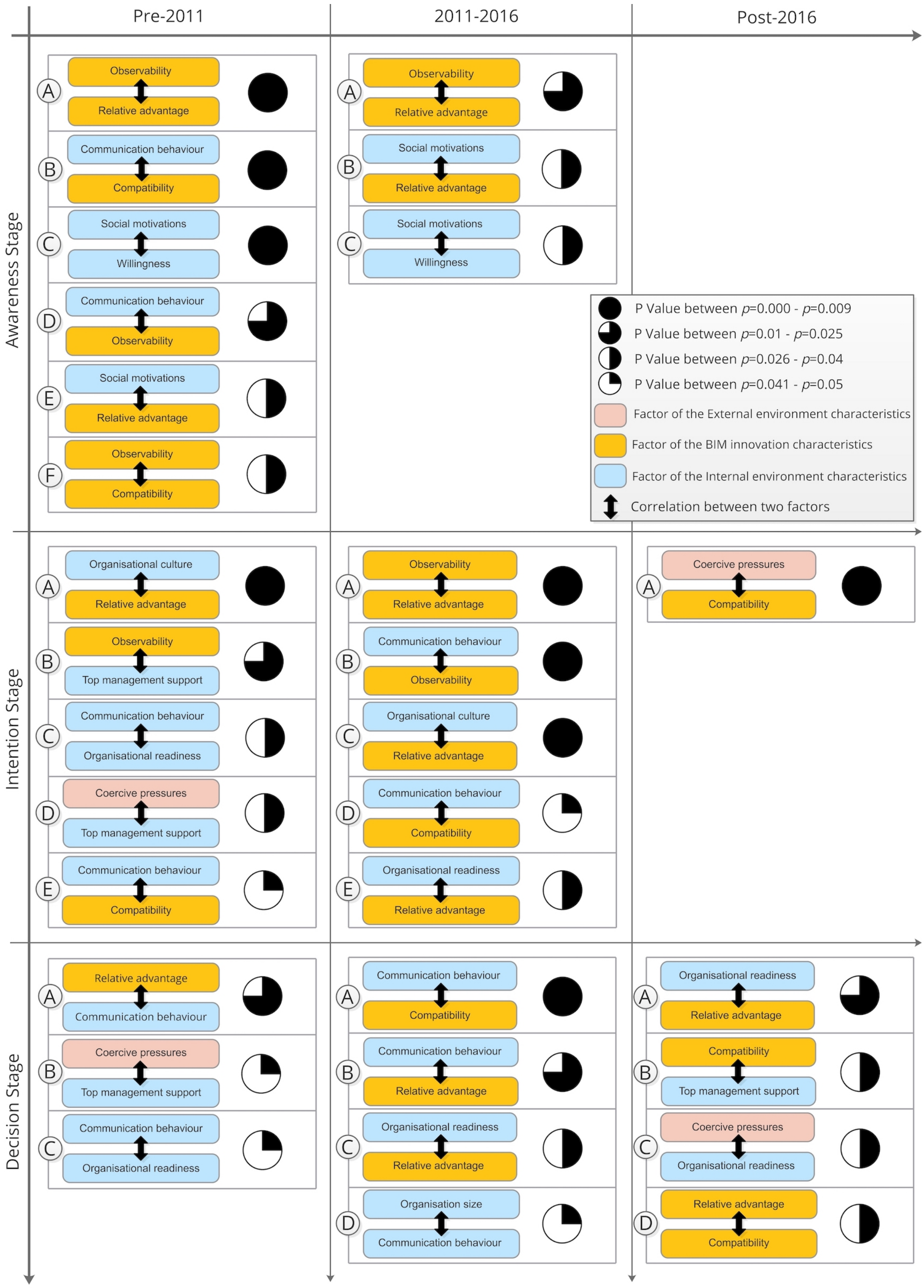


Figure 7.12 A Two-dimensional Characterisation Model profiling BIM adoption process in UK Architecture Sector

7.5 Summary and Conclusion

In this chapter, a Two-dimensional Characterisation Model for the BIM adoption process was developed using knowledge synthesis. First, the identified 11 most influencing factors (i.e., resulted from the Ordinal Logistic Regression analysis of Chapter 6) were tested using Correlation Analysis. The first cycle of the analysis resulted in a set of 39 pairs of strong positive relationships were identified as statistically significant. The second cycle of correlations analysis among the same 11 factors (i.e., while considering the three stages of BIM adoption process, and the time horizon of the UK BIM national initiative) (Ahmed and Kassem, 2018, p.104) resulted in a set of 31 pairs of strong relationships (28 strong positive relationships and 3 negative ones) that were statistically significant. Second, the findings of the correlation analysis were further demonstrated and discussed. Some of the findings showed consistency with previous studies, while other findings indicated the possibility of the influence of certain factors/constructs to have an influence on other stages of BIM adoption process beyond what has been reported in previous literature. Finally, drawing on the triangulation of the results and findings – using knowledge synthesis approach by cross-correlating the values of the individual factors and pairs of factors – a Two-dimensional Characterisation Model for the BIM adoption process was developed. The proposed model identifies and explains the most influencing factors and their interplay as pairs of factors on the BIM adoption process while considering three ordinal stages (i.e., awareness, intention, and decision) and three-time horizons. This model can help to better understand how pairs of factors can have different effects in various stages across different time horizons.

The result of this analysis showed that some pairs of factors (e.g., Communication behaviour ⟺ Compatibility) have a continuous influence by transferring their effect (a) across three consecutive stages within two periodical time-horizon (i.e., from 'Awareness' to 'Intention' in Pre-2011, then from 'Intention' to 'Decision' in 2011-2016) and (b) across two consecutive periodical time-horizon of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Intention'). Thus, such correlations may (1) prompt the organisations' *awareness* to gain more knowledge about BIM; (2) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (3) enable the architectural organisation to make the decision to adopt BIM.

Also, the two-dimensional model can contribute to profiling the potential variations in the effect of adoption drivers on the different stages of BIM adoption at different time horizons. Hence, Objective 4 of this study is achieved.

These findings will inform developing the Systems Thinking Models (i.e., Objective 6) in the next Chapter.

Chapter 8 | Analysis of Causal Relationships among the Adoption Factors and Use of the Research Findings to Inform BIM Adoption Strategies

8.1 Introduction

This chapter considers the BIM adoption process as a complex system that requires a further understanding of the interrelationships among the different adoption factors within the system. Following the identification of the 11 top factors influencing the BIM adoption process (i.e., Chapter 6) and the analysis of correlations among these factors (i.e., Chapter 7), this chapter aims to achieve the last two objectives (Objectives 5 and 6) of this study:

- "Explore the BIM adoption process as a complex system through the application of structural modelling (i.e. Decision-making trial and evaluation laboratory – DEMATEL) to cluster adoption factors into cause and effect groups, and systems thinking techniques to map causal relationships and develop causal loop diagrams"; and
- "Demonstrate how the results from the developed causal loop diagrams can inform the development and implementation of BIM adoption strategies."

This Chapter is motivated by the need for a further understanding of the BIM adoption process that goes beyond the analysis of the correlation between pairs of factors and the ranking of factors. In particular, there is a need for exploring the complex interdependencies between the adoption factors by considering the BIM adoption process as a complex system. To address this need, this chapter comprises three main sections. **Section 8.2** describes the fuzzy DEMATEL Approach (i.e., The Classic DEMATEL method, and the Fuzzy set theory). **Section 8.3** shows the analysis of the BIM adoption process by employing the fuzzy DEMATEL (F-DEMATEL) Approach. It classifies BIM adoption factors into cause and effect groups and analyses their interdependencies. This includes the questionnaire design and data collection process, the calculation process of the F-DEMATEL method, and the analysis of the evaluation criteria of significance for the nine developed F-DEMATEL Models. Next, summary findings of the F-DEMATEL Models, including the commonalities and differences discussion and constructing the representative scenario of the BIM adoption in the UK architectural sector, are presented. An Exhaustive list of the possible ten scenarios of BIM adoption process in the UK architectural sector is identified according to the F-DEMATEL outcomes. **Section 8.4** shows the development of a Systems Thinking Model of the BIM Adoption Process. A Systems Thinking Model of the whole system of BIM Adoption Process with unspecified time horizon is first developed and analysed. Then, Systems Thinking Models of the three Stages of BIM Adoption Process (i.e. Awareness, Intention, and Decision), each overlapped against three time periods (i.e., pre-mandate, implementation period, post-mandate). A Summary of findings of the Causal-loop Diagrams for the Systems Thinking Models is presented. Finally, a discussion of the results is provided and an approach for their use in informing strategies for BIM adoption is presented. Figure 8.1 shows the Chapter 8 design.

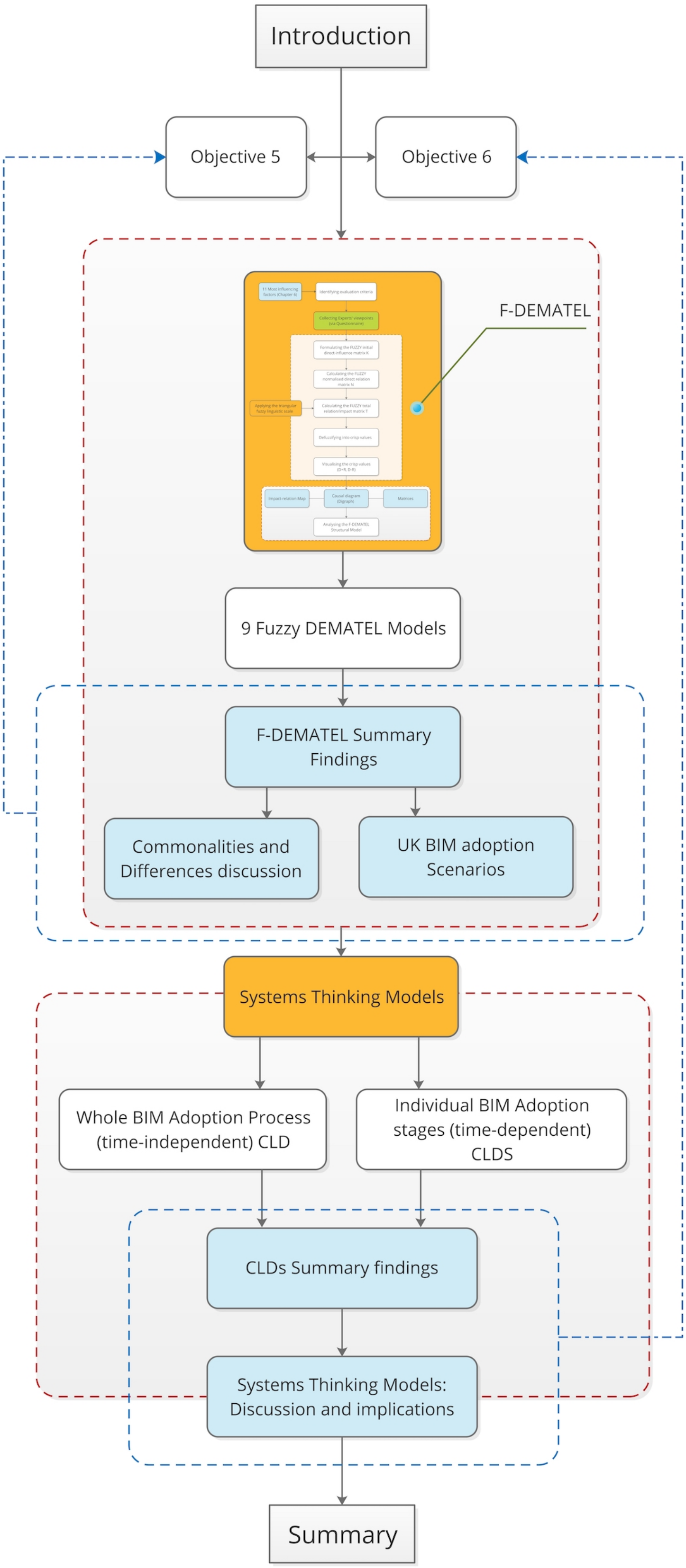


Figure 8.1 Chapter Eight Design structure

8.2 The fuzzy DEMATEL Approach

The decision-making trial and evaluation laboratory (DEMATEL) approach is a technique for constructing and analysing a structural model for investigating the impact of causal relationships amongst an array of interacting factors (Wu and Lee, 2007). It was first used by the Geneva Research Centre in 1973 (Gabus and Fontela, 1973) to investigate and tackle intricate world problems (e.g., hunger, racism, energy, environment protection, etc.) (Fontela and Gabus, 1976). Recently, DEMATEL method has been widely adopted in many countries (e.g., Japan, Taiwan, India, and Korea) to tackle problems in various fields efficiently (Lin, 2013; Chien et al., 2014; Jeng, 2015; Tsai et al., 2015; López-Ospina et al., 2017; Muhammad and Cavus, 2017). More recently, the DEMATEL method has been utilised in many disciplines, for instance: decision-making (Tsai et al., 2015), technology innovation (Chien et al., 2014; ZHAO and YI, 2017), management decision-making (Mardani et al., 2017), airline safety (Chen, 2016), systems engineering (Aviso et al., 2018), knowledge management (Abdullah and Zulkifli, 2018), causal modelling (Ocampo et al., 2018), and many others. In a fuzzy atmosphere, making a decision is very challenging to split interrelating factors (Wu and Lee, 2007). Seyed-Hosseini et al. (2006) suggest to implement the DEMATEL within fuzzy or probabilistic conditions to manage the complication of human judgements in the decision-making process. Lin and Wu (2004) expanded the DEMATEL technique of collective decision-making considering the fuzzy conditions. Therefore, to achieve further accurate analysis, this study will implement the fuzzy DEMATEL method. In the following sections, both the conventional DEMATEL method and the fuzzy set theory will be demonstrated.

8.2.1 The Classic DEMATEL method

DEMATEL aims at directly comparing the interdependency relationship among elements, attributes, and criteria of a system and utilising matrices to analyse the direct and indirect causal relationships and impact level among elements. These relationships are envisaged exploiting the ‘graphical structural matrices’ and ‘causal diagrams’ (i.e., digraphs) to interpret and verify the contextual causal relationships and impact level among the elements in the complex system and support in decision-making (Lee et al., 2010). Hence, DEMATEL can transform a complex system into a clear causal relationship with a well-defined structural model. Simplifying the interactions among elements in the complex system into a justified cause and effect relationship via the interaction impact level among quantified elements assists in discovering the central problem in the complex system and improving direction (Wu and Lee, 2007).

Assume a given system comprises a group of elements $\boldsymbol{E} = [\boldsymbol{e_1}, \boldsymbol{e_2}, \ldots, \boldsymbol{e_n}]$, and specific pair-wise relations are assigned for demonstrating in regard to a arithmetical relation $\boldsymbol{K}$. Following, the technique depicts the relation $\boldsymbol{K}$ as a direct relation matrix which is arranged identically on both dimensions by elements from the group $\boldsymbol{E}$. Next, in addition to the situation where number 0 shows up in the cell $(\boldsymbol{i, j})$, if the input is a positive integral that has the value of (1), the arranged pair $(\boldsymbol{e_i}, \boldsymbol{e_j})$ is in connection to $\boldsymbol{K}$, and (2) there is kind of a connection in element $\boldsymbol{e_i}$ that causes element $\boldsymbol{e_j}$.

This study utilises the DEMATEL method for analysing and investigating the potential interdependencies and relationships among the influential factors/elements on the process of BIM adoption using the refined steps and calculations by Wu and Lee (2007) and Chang et al. (2011) from the previous version originated by Fontela and Gabus (1976) as follows:

Step 1: Identifying the criteria of the influential factors/elements of the complicated system under investigation, and a measurement scale to determine the direction and the degree of influence of the relationships among the elements of the criteria. Then pairwise relationships to be established based on the views and experience of the experts/respondents to perform the pairwise comparisons among the factors. The comparison scale may comprise five levels of influences; as the scores of 0, 1, 2, 3, and 4 denote 'No influence', 'Very low influence', 'Low influence', 'High influence', and 'Very high influence', respectively.

Step 2: Formulating the initial direct-influence matrix $\boldsymbol{K}$, which is an $\boldsymbol{n} \times \boldsymbol{n}$ matrix, determined from the pairwise comparisons of the influences and the directions among the factors of the criteria. $\boldsymbol{K}$= $[\boldsymbol{k_{ij}}]_{\boldsymbol{n \times n}}$, where $\boldsymbol{k_{ij}}$ is the level of influence of criterion $\boldsymbol{i}$ exerts on criterion $\boldsymbol{j}$ (Equation 8.1).

Equation 8.1 Initial direct-influence matrix *K*

$$K = \begin{pmatrix} 0 & k_{12} & \cdots & k_{1n} \\ k_{21} & 0 & \cdots & k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ k_{n1} & k_{n2} & \cdots & 0 \end{pmatrix} \tag{0.1}$$

Step 3: Calculating a normalised direct relation matrix $\boldsymbol{N}$ based on using Equation 8.2 and

Equation 8.3 , where all main diagonal elements are equal to zero.

Equation 8.2

$$\lambda = \frac{1}{Max_{1 \le i \le n}\left(\sum_{j=1}^{n} k_{ij}\right)} \quad , \qquad i, j \in \{1, 2, ..., n\} \tag{0.2}$$

Equation 8.3

$$N = \lambda \times K \tag{0.3}$$

Step 4: Calculating the total relation/impact matrix $\boldsymbol{T}$ using Equation 8.4, where $\boldsymbol{I}$ is the identity matrix.

Equation 8.4

$$T = N\left(I - N\right)^{-1} \tag{0.4}$$

Step 5: Calculating the sum of the values of each row $\boldsymbol{D}$ and each column $\boldsymbol{R}$ separately of the total relation matrix, $\boldsymbol{D_i}$ and $\boldsymbol{R_j}$ denote the sum of rows (i.e., direct influences) and columns (i.e., indirect influences) respectively, using Equation 8.5,

Equation 8.6, and Equation 8.7.

Equation 8.5

$$T = \left[t_{ij} \right]_{n \times n} \quad , \quad i,j \in \{1,2,...,n\} \qquad (0.5)$$

Equation 8.6 Direct influences

$$D_i = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} \quad , \quad i,j \in \{1,2,...,n\} \qquad (0.6)$$

Equation 8.7 Indirect influences

$$R_J = \left[\sum_{J=1}^{n} t_{ij} \right]_{1 \times n} \quad , \quad i,j \in \{1,2,...,n\} \qquad (0.7)$$

Step 6: Visualising the DEMATEL cause and effect digraph by plotting the dataset of (***D*+*R*, *D*-*R***), in which the horizontal axis vector (***D*+*R***) is defined by adding ***D*** to ***R***, that represents the total 'Importance' level of each criterion/factor. Likewise, the vertical axis vector (***D*-*R***) is defined by subtracting ***R*** from ***D***, that represents the 'Relation' and may categorise criteria into cause-and-effect groups. When the (***D*-*R***) is positive, the criterion is belonged to the 'cause group', and when (***D*-*R***) is negative, it belongs to the 'effect group'.

8.2.2 The fuzzy logic (Fuzzy set theory)

Having described the conventional DEMATEL method and its calculating steps, in this section the Fuzzy theory and its Fuzzy set of numbers is demonstrated and how it can be combined with the conventional DEMATEL method to solve potential imprecision in real-world judgment by de-fuzzifying the fuzzy numbers into crisp numbers.

In many industries, numerous business organisations rely on 'group decision-making' to locate an agreeable resolution in actual decision-making problems. However, in decision-making problem associated with complex systems, the assessment presented by decision-makers or experts on subjective principles of a specific item is constantly communicated in linguistic expressions rather than crisp values, depending on expertise and knowledge (Lin, 2013). Such linguistic assessments are imprecise and obscure that cause additional investigation and analysis is difficult to carry out. The reasons for inaccuracy comprise: non-identifiable information, inadequate information, difficulty in obtaining information, and partial lack of knowledge (Bellman and Zadeh, 1970). To address such sort of inaccuracy problem, the fuzzy set theory was first developed by Zadeh (1965) as an arithmetical method to signify and manage vagueness in decision-making. Therefore, applying the fuzzy set theory helps in quantifying vague perceptions related to human's self-judgments (Wu and Lee, 2007). Arithmetically, every number in the fuzzy set between 0 and 1 denotes a fractional fact, while crisp sets conform to 0 or 1 binary logic (Wu and Lee, 2007; Lin, 2013).

The fuzzy linguistic process involves transforming linguistic wording into fuzzy numbers after which de-fuzzifying these fuzzy numbers to gain accurate values (Tsaur and Kuo, 2011; Lee et al., 2014)(Table 8.1). The defuzzification solution implemented in the current study utilises the minimum and maximum fuzzy number to define the left and right edge values respectively. The total integral value is calculated dependent on the weighted average of the membership function. Determining the crisp values of the fuzzy set numbers $\tilde{A}$ are described in the following steps using the triangular fuzzy numbers $\tilde{N}$ method (Chang et al., 2011; Lee et al., 2014):

Table 8.1 The triangular fuzzy linguistic scale set

Linguistic terms/influence	Score	Triangular Fuzzy Number
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0, 0.25)
Low influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1.00)
Very high influence	4	(0.75, 1.00, 1.00)

Step 1: Normalisation (Equation 8.8)

Equation 8.8 Normalisation

$$
\begin{aligned}
k_{lj} &= (l_{ij} - l_i^{\min}) / \Delta_{\min}^{\max} \\
k_{mj} &= (m_{ij} - l_i^{\min}) / \Delta_{\min}^{\max} \\
k_{pj} &= (p_{ij} - l_i^{\min}) / \Delta_{\min}^{\max}
\end{aligned}
\tag{0.8}
$$

Where $p_i^{\max} = \max p_j^i \quad , \quad l_i^{\min} = \min l_j^i \quad , \quad \Delta_{\min}^{\max} = \min l_{ij}$

Step 2: Calculating the left/low (*ls*) and right/high (*ps*) normalised values/thresholds (Equation 8.9):

Equation 8.9

$$
\begin{aligned}
Kls_j^n &= k_{mj} / 1 + k_{mj} - k_{lj} \\
Kps_j^n &= k_{pj} / 1 + k_{pj} - k_{mj}
\end{aligned}
\tag{0.9}
$$

Step 3: Calculating the crisp values (Equation 8.10):

Equation 8.10 Crisp values

$$
k_j^{crisp} = \left[k_j^{ls} \left(1 - k_j^{ls} \right) + kps_{ij}^n \times kps_{ij}^n \right] / \left[1 - k_j^{ls} + k_j^{ps} \right] \tag{0.10}
$$

Step 4: Calculating the integral crisp values based on various opinions of the respondents (Equation 8.11):

Equation 8.11 Integral crisp values

$$
f_{ij} = l_i^{\min} + k_j^{crisp} \times \Delta_{\min}^{\max} \tag{0.11}
$$

8.3 Data analysis: The Fuzzy DEMATEL procedures implementation and Discussion

This section includes the questionnaire design and data collection process, the calculation process of the fuzzy DEMATEL method, and the analysis of the evaluation criteria of significance for the nine developed Fuzzy DEMATEL Models.

8.3.1 Fuzzy DEMATEL questionnaire design and data collection

This study has employed a second questionnaire survey to collect the data required for the F-DEMATEL method for analysing and investigating the potential interdependencies and relationships among the influential factors/elements on the process of BIM adoption. A structured questionnaire that includes two sections was devised and used to collect the empirical data (See the whole questionnaire in Appendix D). The first section was aimed at obtaining the respondent agreement with 110 various statements (i.e., pair-wise relationship between two potentially interacting factors, i.e. 11 factors x 10 relationships) using a five-point Likert scale. Definitions of the most influencing factors on the decision to adopt BIM were presented to deliver a brief idea about each of the factors (Table 8.2). The second section of the questionnaire was intended to capture demographic information (e.g., gender, job title, and age).

The sampling criterion required the respondents to be knowledgeable about the process of BIM adoption within organisations (e.g. as internal or external change agents). The questionnaire is emailed to qualified potential respondents. An invitation letter is enclosed into the email with a website hyperlink that direct participants to the online questionnaire. The data were collected from mid-October to early November 2018 using the same monitored and administered online tool (Google Forms). 12 valid responses were returned and two incomplete responses were discarded.

Table 8.2 Definitions of the most influencing factors/ evaluation criteria of the F-DEMATEL Questionnaire

Factors	Definitions
Willingness to adopt BIM (F1)	Refers to the favourable or unfavourable attitude of organisation or a decision-making unit towards the innovation/ BIM.
Communication behaviour of an organisation (F2)	The degree of openness and engagement of an organisation with social groupings and networks interested in innovation adoption and promotion.
Observability of BIM benefits (F3)	The degree to which the results from innovation/BIM adoption are visible and tangible.
Compatibility of BIM (F4)	The degree to which an innovation/BIM aligns with potential adopter's previous experiences and current needs and values.
Social motivations among organisation's members (F5)	The motivation to engage in behaviours that benefit others such as considering others' perspectives, stimulating knowledge exchange, and focusing on collective goals.
Relative advantage of BIM (F6)	The degree to which an innovation/BIM is perceived as being better than the system/practice it replaces.
Organisational culture (F7)	The shared norms, beliefs, principles, and traditions - held by the members of an organisational practice – which contribute to the members' understanding of the organisational functioning.
Top management support (F8)	The degree to which senior management understands the importance of the innovation/BIM function and the extent to which they are involved into promoting the system adoption.
Organisational readiness (F9)	The extent to which organisational members are psychologically and behaviourally prepared to implement a change, their mutual determination to perform the change, and their mutual faith in their aggregate capacity to achieve the change.
Coercive pressures (Governmental mandate, informal mandate) (F10)	The formal and informal forces applied to organisations by other organisations (public and private clients/employers, etc.).
Organisation size (F11)	The total number of full-time members of staff of an organisation (e.g., micro, small, medium, and large).

8.3.2 The calculation process of fuzzy DEMATEL method

The F-DEMATEL method was applied in this study following the five steps mentioned in Section 8.2.1 and their pertinent equations. The four steps of Section 8.2.2 were applied – using the fuzzy linguistic scale set – to de-fuzzifying the fuzzy total relation/impact matrix ***T*** into crisp values. As shown in Table 8.3, nine cycles of these sequential steps were applied resulting in a set of nine matrices. Each of the resultant matrices will be presented in the following sections. Figure 8.2 shows the Fuzzy DEMATEL process.

Table 8.3 The included BIM Adoption Process Factors in F-DEMATEL Matrices

Stage	Time horizon	Involved factors	Matrix size
Whole system	time-independent	Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Compatibility of BIM (F4), Social motivations among organisation's members (F5), Relative advantage of BIM (F6), Organisational culture (F7), Top management support (F8), Organisational readiness (F9), Coercive pressures (Governmental mandate, informal mandate) (F10), and Organisation size (F11).	11×11
Awareness	Pre-2011 period	Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Relative advantage of BIM (F6), Compatibility of BIM (F4), and Social motivations among organisation's members (F5).	6×6
	2011-2016 period	Willingness to adopt BIM (F1), Social motivations among organisation's members (F5), Observability of BIM benefits (F3), and Relative advantage of BIM (F6).	4×4
	Post-2016 period	The targeted sample did not statistically indicate any adequate representative responses of BIM Awareness in this period.	
Intention	Pre-2011 period	Communication behaviour of an organisation (F2), Compatibility of BIM (F4), Organisational readiness (F9), Relative advantage of BIM (F6), Organisational culture (F7), Observability of BIM benefits (F3), Top management support (F8), and Coercive pressures (Governmental mandate, informal mandate) (F10).	8×8
	2011-2016 period	Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Compatibility of BIM (F4), Relative advantage of BIM (F6), Organisational culture (F7), and Organisational readiness (F9).	6×6
	Post-2016 period	Compatibility of BIM (F4) and Coercive pressures (Governmental mandate, informal mandate) (F10).	2×2
Decision	Pre-2011 period	Communication behaviour of an organisation (F2), Relative advantage of BIM (F6), Organisational readiness (F9), Top management support (F8), and Coercive pressures (Governmental mandate, informal mandate) (F10).	5×5
	2011-2016 period	Communication behaviour of an organisation (F2), Organisation size (F11), Relative advantage of BIM (F6), Compatibility of BIM (F4), and Organisational readiness (F9).	5×5
	Post-2016 period	Relative advantage of BIM (F6), Compatibility of BIM (F4), Organisational readiness (F9), Top management support (F8), and Coercive pressures (Governmental mandate, informal mandate) (F10).	5×5

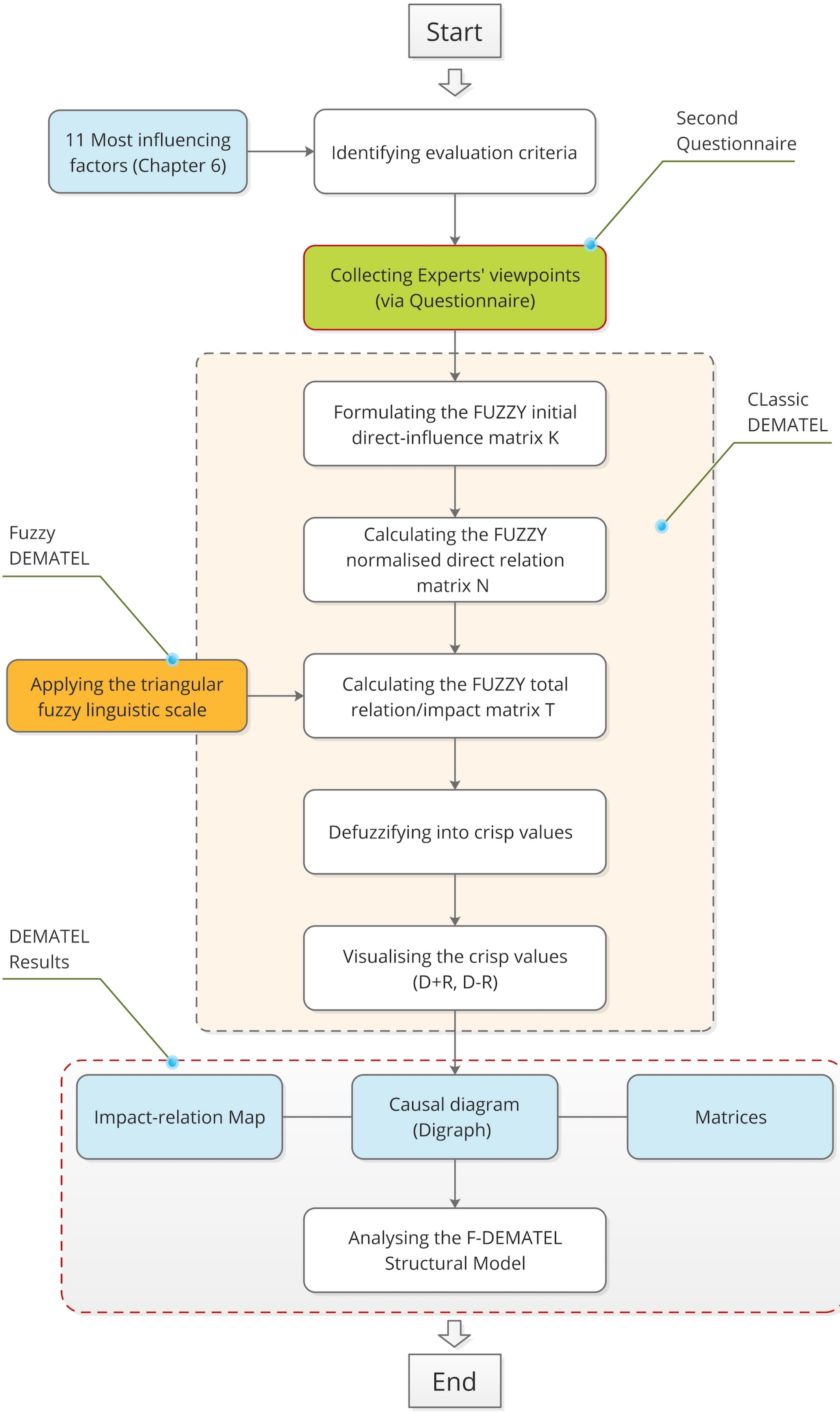


Figure 8.2 The Process of Fuzzy DEMATEL method

8.3.3 Analysing the evaluation criteria of significance (Findings and Discussions of the Fuzzy DEMATEL Models)

Having conducted the Fuzzy-DEMATEL (F-DEMATEL) method and its steps (Section 8.3.2 aforementioned) on nine formulated models of interacting factors (i.e. one model that includes the whole 11 most influential factors, and eight separate models of each stage of the three BIM adoption process against three-time horizons), the following subsections will present the findings of each of the nine analysed models.

8.3.3.1 The F-DEMATEL model of the whole system of BIM adoption process (11 factors/ time-independent)

In this model, F-DEMATEL were employed to investigate the causal relationships and analyse the interdependencies among the 11 most influential factors (identified in Chapter 6 Section 6.3). These factors are: Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Compatibility of BIM (F4), Social motivations among organisation's members (F5), Relative advantage of BIM (F6), Organisational culture (F7), Top management support (F8), Organisational readiness (F9), Coercive pressures (Governmental mandate, informal mandate) (F10), and Organisation size (F11).

In the causal diagram (Impact-digraph Map criteria using DEMATEL) (Figure 8.3), the values of (D+R) and (D-R) are represented by the horizontal axis and the vertical axis, respectively. The (D+R) value determines the degree of significance of the factor measured on the process of BIM adoption. The (D-R) value categorises the factors into a cause group and effect group. The results of conducting the F-DEMATEL method have revealed two groups of factors (Table 8.4 and Table 8.5): *cause group (influencing factors)* with high centrality degree and positive causal degree; and *effect group (affected factors)* with high centrality degree and negative causal degree, which are interdependent. In a descending order of the average of each factor influence on all other factors, the cause group factors are Organisation size (F11), Coercive pressures (Governmental mandate, informal mandate) (F10), Relative advantage of BIM (F6), Observability of BIM benefits (F3), Compatibility of BIM (F4), and Organisational readiness (F9). The effect group of factors are Willingness to adopt BIM (F1), Top management support (F8), Communication behaviour of an organisation (F2), Social motivations among organisation's members (F5), and Organisational culture (F7). The cause factors have an influence on the whole system, and the effect factors tend to be easily influenced by the other factors. The threshold value – as an exclusion criterion is calculated based on the average of all the elements in matrix T – of this model is 0.052 to exclude the weak influence of interrelationships among the constructs/factors. The causal diagram can further be divided into four quadrants (Figure 8.3):

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), *Observability of BIM benefits* (F3), and *Organisational readiness* (F9). These cause factors influence most of the effect factors in Quadrant IV and their resolutions contribute to unlock many factors within the system. Hence, these factors should be prioritised and addressed first in a BIM adoption strategy.
- Quadrant II: Includes the 'Driving' factors - or autonomous givers - with low prominence and high relation. These factors are *Organisation size* (F11), *Coercive pressures* (F10), and *Compatibility of BIM* (F4). These factors are somewhat independent (e.g. cannot be influenced easily) but they have influence on many other factors with the system (i.e., effect factors in Quadrant IV).
- Quadrant III: It contains independent factors or autonomous receivers. It includes only one factor, *Organisational culture* (F7), which is relatively an independent factor due to its low prominence and low relation. It can either be individually solved or may be influenced only by a few other factors within the system (i.e., F1 and F8 of effect Quadrant IV).
- Quadrant IV: Includes the 'effect' factors with high prominence and low relation. This quadrant comprises of four factors; *Willingness to adopt BIM* (F1), *Top management support* (F8), *Communication behaviour of an organisation* (F2), *and Social motivations among organisation's members* (F5). These factors are influenced by other factors and represent a core cluster to

must be managed. However, they cannot be addressed directly. This cluster include F1 (*Willingness to adopt BIM*) which has the highest influence.

All the three factors in the first quadrant (F6, F3, and F9) and second quadrant (F11, F10, and F4) that represent the core factors and the driving factors, respectively, affect the four factors of the fourth quadrant (F1, F8, F2, and F5) (Figure 8.4). Thus, this suggests that to address the effect group factors in BIM adoption process, it is necessary to first target the core factors and the driving factors that must be given more attention by decision makers within the adopting organisations.

In this sense, promoting BIM characteristics [i.e., Relative advantage (F6), Observability (F3), and Compatibility of BIM (F4)] may separately affect the internal environment characteristics [i.e., Organisational readiness (F9), Organisational culture (F7), Social motivations among organisation's members (F5), Communication behaviour of an organisation (F2), Top management support (F8), and Willingness to adopt BIM (F1)]. This involves, for example, how the perceived benefits obtained from adopting BIM (F6), may contribute to increasing the openness and engagement of the potential adopters with social groupings and networks interested in BIM adoption and promotion (F2); stimulate more Willingness to adopt BIM (F1); and invite more executive support (F8) in the architectural organisations that facilitates the BIM adoption process. Similarly, demonstrating visible and tangible results of successful BIM adoption examples of other organisations (F3), and clarifying how can BIM be aligned with the potential adopter's previous experiences and current needs and values (F4), may affect (F8) and (F1).

Combining the shared norms, beliefs, and traditions (F7), held by the members of organisational practice, with *Organisational readiness* will contribute to stimulating *Willingness to adopt BIM* (F1). Consequently, strengthening BIM characteristics (F6, F3, and F4) together with organisational characteristics (F9, F7, F5, F2, and F1) may invite more executive support in the organisations [i.e., *Top management support* (F8)].

Moreover, the simultaneous influence of BIM mandate [i.e., *Coercive pressures (Governmental mandate, informal mandate)* (F10)], as an independent factor, may exert additional influence on executive support in organisations (F8) that greatly supports the process of BIM adoption. Such this mandatory implementation of BIM in public projects besides the additional incentives for the bidding process of projects that utilise BIM technology, may promote the diffusion of BIM across the industry and produce an enhanced external environment for BIM implementation.

Organisation size (F11) also has an independent influence on all other factors. It can be considered to measure how various factors influencing each other according to the different sizes of organisations (i.e., micro, small, medium, and large).

It can be concluded that it is not necessarily that BIM Awareness to be triggered only by the internal environment characteristics of the organisation as stated in the existing literature [e.g., (Hameed et al., 2012; Rogers, 2003)], but also by BIM characteristics (i.e., innovation characteristics).

Table 8.4 The De-Fuzzified total relation matrix T of the whole system of BIM adoption process (11 factors)

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1. Willingness	0	0.061	0.050	0.045	0.054	0.047	0.061	0.059	0.056	0.042	0.031
F2. Communication behaviour	0.071	0	0.064	0.060	0.063	0.059	0.058	0.061	0.063	0.044	0.027
F3. Observability of BIM	0.073	0.064	0	0.063	0.060	0.065	0.050	0.078	0.050	0.042	0.029
F4. Compatibility of BIM	0.068	0.057	0.057	0	0.061	0.056	0.050	0.069	0.051	0.042	0.029
F5. Social motivations	0.074	0.070	0.050	0.047	0	0.056	0.056	0.061	0.049	0.038	0.029
F6. Relative advantage of BIM	0.077	0.073	0.065	0.069	0.058	0	0.055	0.074	0.057	0.044	0.030
F7. Organisational culture	0.073	0.065	0.046	0.043	0.065	0.056	0	0.066	0.058	0.043	0.028
F8. Top management support	0.074	0.069	0.051	0.043	0.053	0.045	0.059	0	0.061	0.043	0.035
F9. Organisational readiness	0.071	0.065	0.057	0.052	0.059	0.066	0.051	0.065	0	0.042	0.032
F10. Coercive pressures	0.074	0.066	0.047	0.044	0.059	0.052	0.058	0.079	0.058	0	0.036
F11. Organisation size	0.064	0.064	0.050	0.047	0.057	0.044	0.057	0.059	0.049	0.043	0

Table 8.5 The F-DEMATEL results of the whole system of BIM adoption process (11 factors)

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F1. Willingness	0.529	0.743	1.272	11	-0.214	Effect
F2. Communication behaviour	0.594	0.678	1.272	3	-0.084	Effect
F3. Observability of BIM	0.597	0.559	1.156	2	0.038	Cause
F4. Compatibility of BIM	0.563	0.535	1.099	7	0.028	Cause
F5. Social motivations	0.554	0.611	1.164	9	-0.057	Effect
F6. Relative advantage of BIM	0.626	0.569	1.195	1	0.056	Cause
F7. Organisational culture	0.565	0.576	1.141	6	-0.011	Effect
F8. Top management support	0.555	0.694	1.249	8	-0.139	Effect
F9. Organisational readiness	0.582	0.576	1.158	5	0.006	Cause
F10. Coercive pressures	0.592	0.444	1.036	4	0.149	Cause
F11. Organisation size	0.553	0.325	0.878	10	0.228	Cause

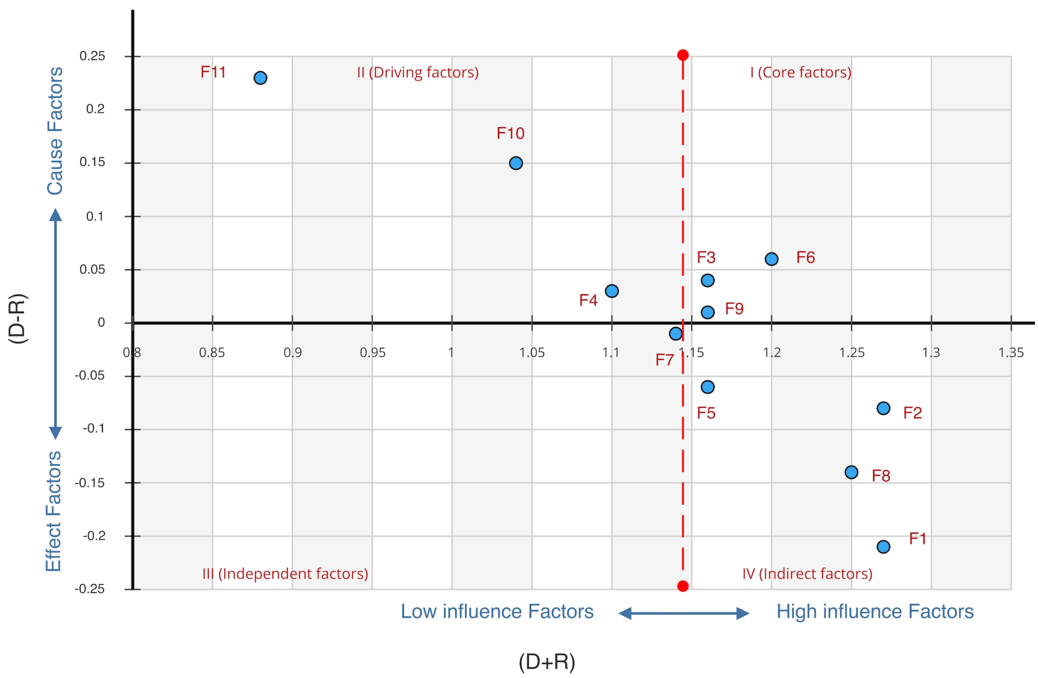


Figure 8.3 Causal diagram (Digraph) of the interdependent cause and effect relationships among the most influencing factors affecting the decision to adopt BIM by architectural organisations

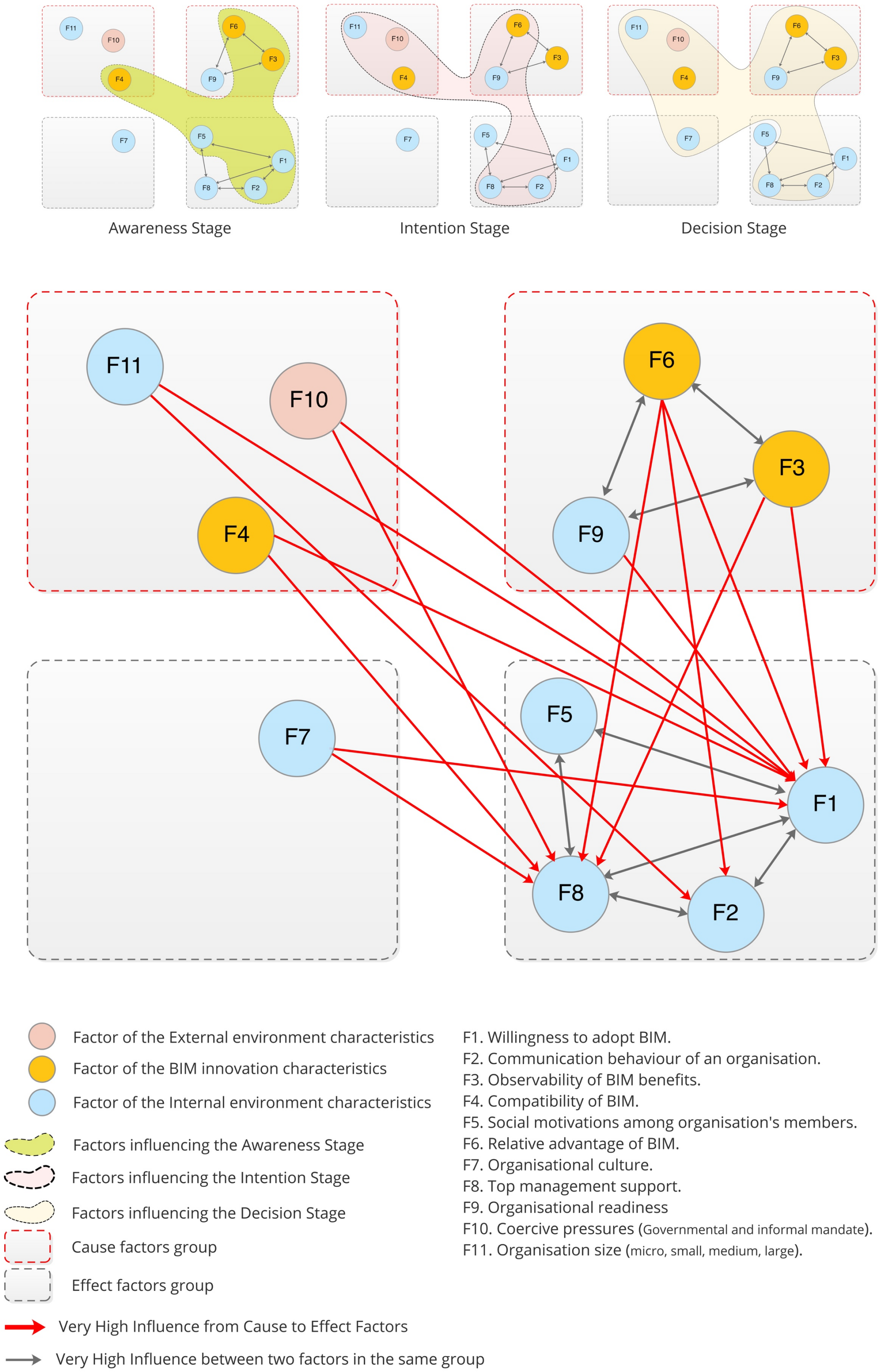


Figure 8.4 Impact Relation Map depicts the cause and effect relationships and interdependencies among the most influencing factors affecting the process of BIM adoption

8.3.3.2 The F-DEMATEL model of the Awareness Stage for the Pre-2011 Period

Six factors, Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Compatibility of BIM (F4), Social motivations among organisation's members (F5), and Relative advantage of BIM (F6), were included in the F-DEMATEL model of the Awareness Stage for the Pre-2011 period. The results of conducting the FDEMATEL method have revealed two groups of factors (Table 8.6 and Table 8.7): *cause group*, which comprises the following factors ranked in descending order: Relative advantage of BIM (F6), Observability of BIM benefits (F3), Communication behaviour of an organisation (F2), and Social motivations among organisation's members (F5). The *effect group* of factors includes: Compatibility of BIM (F4) and Willingness to adopt BIM (F1). The threshold value of this model is 0.119 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.5 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It includes the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), Observability of BIM benefits (F3), and *Communication behaviour of an organisation* (F2) which are the cause factors influencing all other factors and can unlock them in a BIM adoption strategy. In this cluster, factor (F6) is the 'most influencing' factor as it has the highest relation with other factors while factor (F2) is the 'most important' factor with the highest centrality degree.
- Quadrant II: Only one 'Driving' factor [i.e., *Social motivations among organisation's members* (F5)] is included in this quadrant. This factor mainly affects (F1).
- Quadrant III: It contains two 'effect' factors, *Willingness to adopt BIM* (F1) and *Compatibility of BIM* (F4), which are affected by other factors.
- Quadrant IV: This quadrant does not include any factor.

Based on the mentioned results, the Awareness of BIM in Pre-2011 period occurred when *BIM characteristics* [i.e., *Relative advantage of BIM* (F6) and *Observability of BIM* benefits (F3)] stimulated a specific *Internal Environment characteristic* [i.e., *Communication behaviour of an organisation* (F2)] after organisations had been exposed to BIM innovation. Together these factors, with the contribution from other independent factors [i.e., *Social motivations among organisation's members* (F5) and *Compatibility of BIM* (F4)], attracted the attention of the organisations' decision-making units (i.e., decision-makers) who improved their knowledge and awareness of BIM [i.e., *Willingness to adopt BIM* (F1)](Figure 8.6).

Table 8.6 The De-Fuzzified total relation matrix T of the Awareness Stage for the Pre-2011 Period

Factors	F1	F2	F3	F4	F5	F6
F1. Willingness	0	0.130	0.113	0.104	0.118	0.103
F2. Communication behaviour	0.161	0	0.154	0.147	0.144	0.139
F3. Observability of BIM	0.171	0.148	0	0.156	0.138	0.155
F4. Compatibility of BIM	0.155	0.127	0.137	0	0.140	0.131
F5. Social motivations	0.172	0.160	0.121	0.116	0	0.134
F6. Relative advantage of BIM	0.177	0.168	0.157	0.172	0.135	0

Table 8.7 The F-DEMATEL results of the Awareness Stage for the Pre-2011 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F1. Willingness	0.615	0.884	1.499	6	-0.269	Effect
F2. Communication behaviour	0.796	0.783	1.579	3	0.012	Cause
F3. Observability of BIM	0.818	0.730	1.548	2	0.088	Cause
F4. Compatibility of BIM	0.738	0.742	1.480	5	-0.005	Effect
F5. Social motivations	0.749	0.723	1.472	4	0.026	Cause
F6. Relative advantage of BIM	0.858	0.711	1.569	1	0.147	Cause

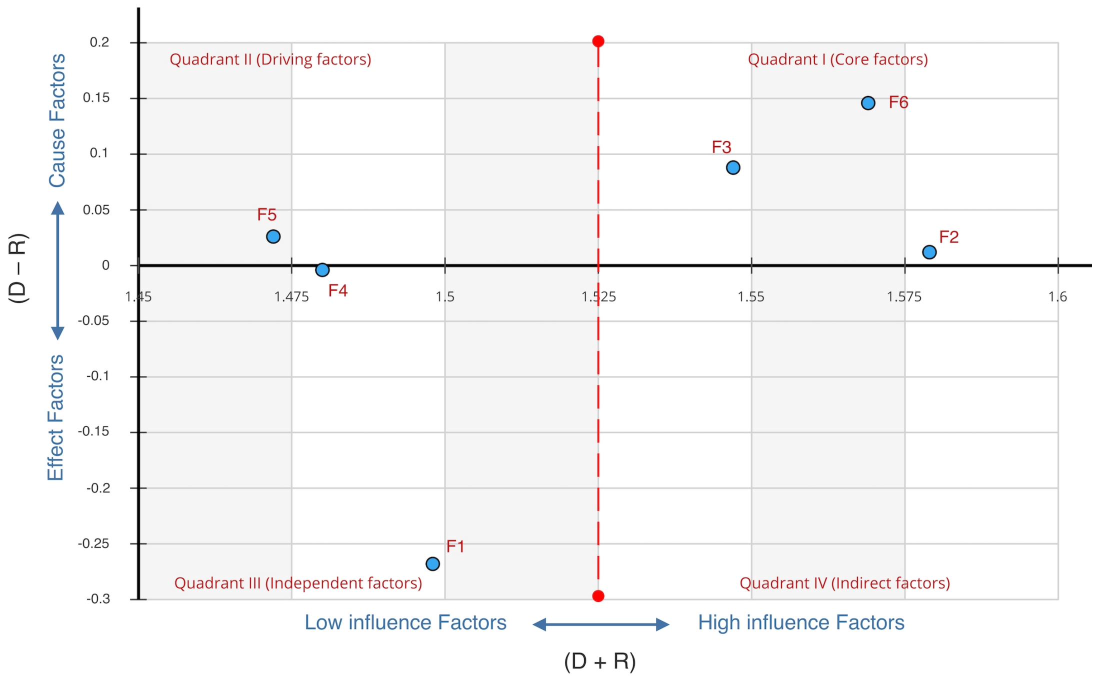


Figure 8.5 Causal diagram (Digraph) of the Awareness Stage for the Pre-2011 Period

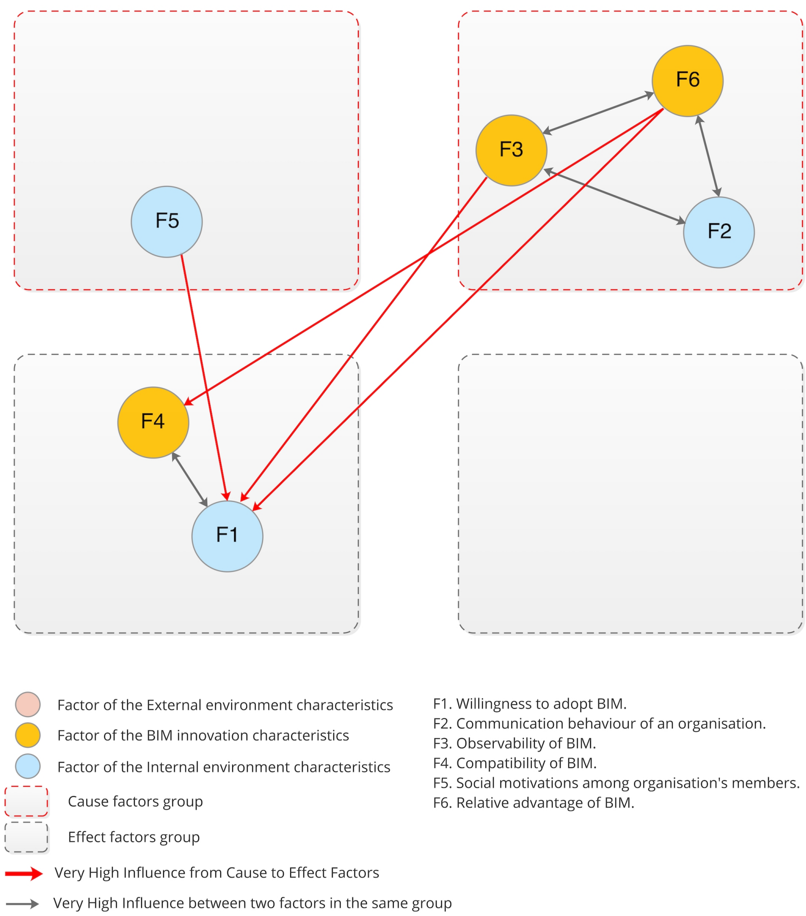


Figure 8.6 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Awareness Stage for the Pre-2011 Period

8.3.3.3 The F-DEMATEL model of the Awareness Stage for the 2011-2016 Period

In this F-DEMATEL model, four factors were included, Willingness to adopt BIM (F1), Observability of BIM benefits (F3), Social motivations among organisation's members (F5), and Relative advantage of BIM (F6). The results of conducting the FDEMATEL method have revealed two groups of factors (Table 8.8 and Table 8.9): *cause group*, which comprises the following factors ranked in descending order: Relative advantage of BIM (F6), Social motivations among organisation's members (F5), and Observability of BIM benefits (F3), and the *effect group* which includes only one factor: Willingness to adopt BIM (F1). The threshold value of this model is 0.516 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.7 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It includes the 'Core' factors with high prominence and high relation. These are: *Relative advantage of BIM* (F6), *Social motivations among organisation's members* (F5), and *Observability of BIM benefits (F3)* which are the cause factors influencing and driving factor (F1) of quadrant III. In this cluster, factor (F6) is the 'most influencing' and 'most important' factor as it has the highest relation with other factors and for its highest centrality degree.
- Quadrant III: It contains only one 'effect' factor, *Willingness to adopt BIM* (F1), which is affected by other factors.

The Awareness of BIM in the 2011-2016 period occurred when BIM characteristics [i.e., *Relative advantage of BIM* (F6) and Observability of BIM benefits (F3)] stimulated a specific Internal Environment characteristic [i.e., *Social motivations among organisation's members* (F5)] after organisations had been exposed to BIM innovation. These factors (F6, F5, and F3) attracted the attention of the organisations' decision-making units (i.e., decision-makers) who became more knowledgeable and aware of BIM [i.e., *Willingness to adopt BIM* (F1)] (Figure 8.8).

Table 8.8 The De-Fuzzified total relation matrix T of the Awareness Stage for the 2011-2016 Period

Factors	F1	F3	F5	F6
F1. Willingness	0	0.430	0.429	0.362
F3. Observability of BIM	0.597	0	0.426	0.536
F5. Social motivations	0.606	0.520	0	0.410
F6. Relative advantage of BIM	0.606	0.541	0.534	0

Table 8.9 The F-DEMATEL results of the Awareness Stage for the 2011-2016 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F1. Willingness	1.369	1.957	3.327	4	-0.588	Effect
F3. Observability of BIM	2.231	2.163	4.394	2	0.068	Cause
F5. Social motivations	2.207	2.060	4.267	3	0.148	Cause
F6. Relative advantage of BIM	2.455	2.082	4.537	1	0.372	Cause

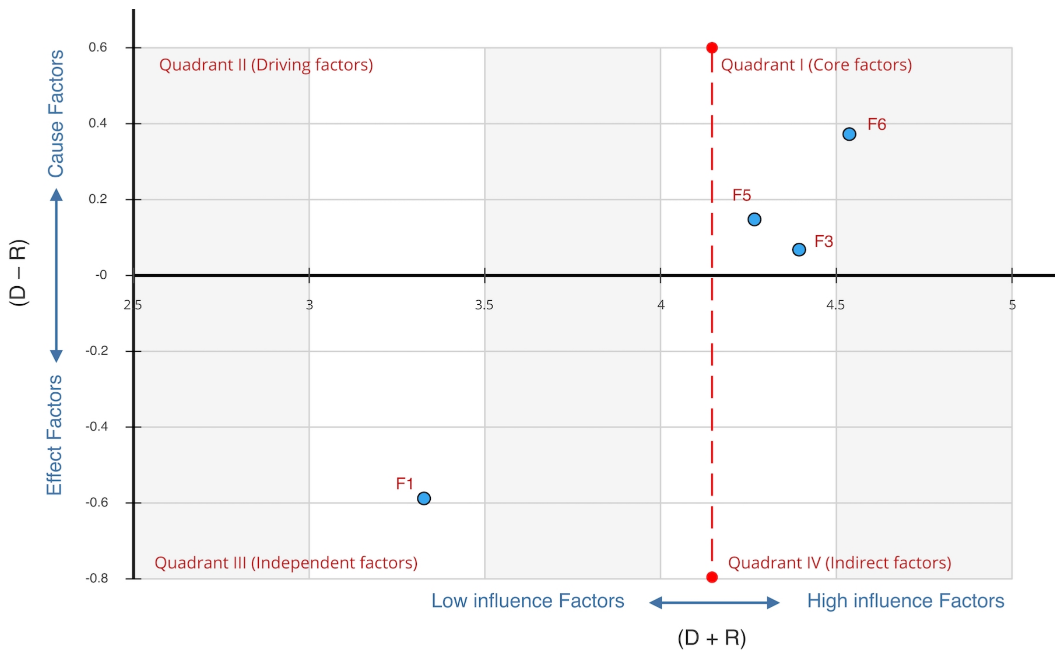


Figure 8.7 Causal diagram (Digraph) of the Awareness Stage for the 2011-2016 Period

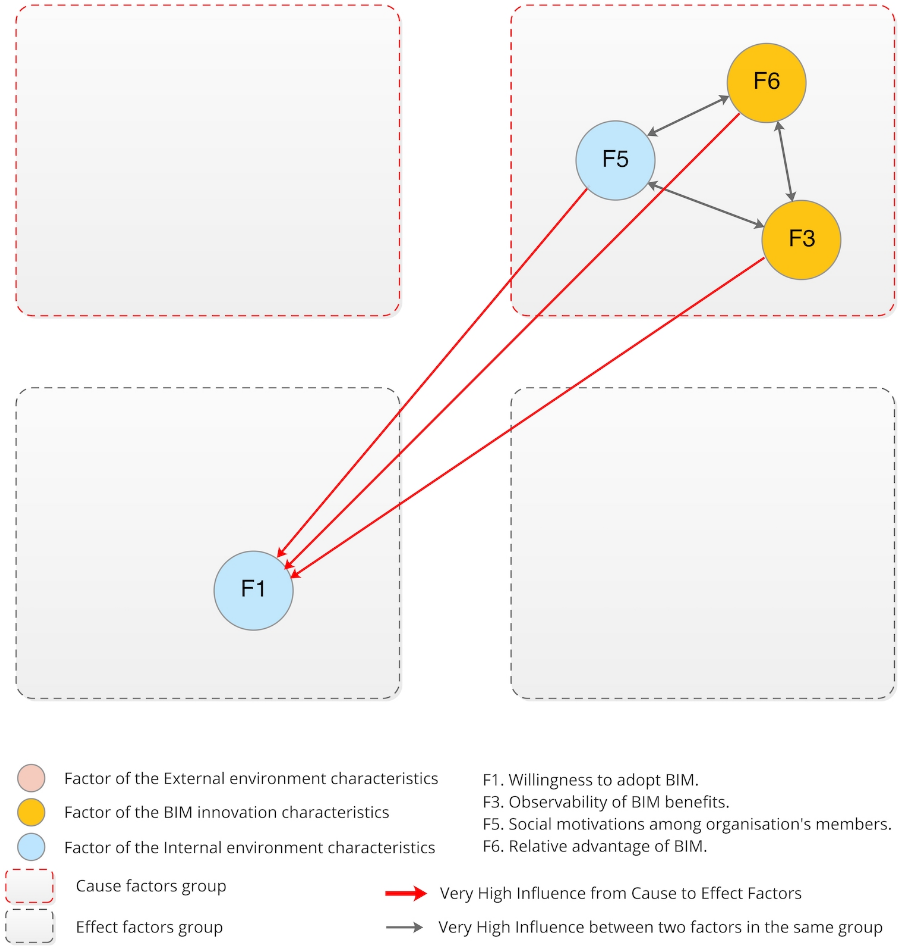


Figure 8.8 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Awareness Stage for the 2011-2016 Period

8.3.3.4 The F-DEMATEL model of the Intention Stage for the Pre-2011 Period

Eight factors, Communication behaviour of an organisation (F2), *Observability of BIM benefits* (F3), *Compatibility of BIM* (F4), *Relative advantage of BIM* (F6), *Organisational culture* (F7), *Top management support* (F8), *Organisational readiness* (F9), and *Coercive pressures (Governmental mandate, informal mandate)* (F10) were included in the F-DEMATEL model of the Intention Stage for the Pre-2011 period. The results of conducting the FDEMATEL method have revealed two groups of factors (Table 8.10 and Table 8.11): the *cause group*, which comprises the following factors ranked in a descending order: *Coercive pressures (Governmental mandate, informal* *mandate)* (F10), *Relative advantage of BIM* (F6), *Observability of BIM benefits* (F3), *Organisational culture* (F7), and *Compatibility of BIM* (F4). The *effect group* of factors includes: *Organisational readiness* (F9), Communication behaviour of an organisation (F2), and *Top management support* (F8). The threshold value of this model is 0.145 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.10 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), and *Observability of BIM benefits* (F3), which are the cause factors influencing most other factors and can unlock them in a BIM adoption strategy. In this cluster, (F6) is the 'most important' factor as it has the highest centrality degree.
- Quadrant II: Includes the 'Driving' factors with low prominence and high relation. These factors are *Coercive pressures* (F10), *Organisational culture* (F7), and *Compatibility of BIM* (F4), which only affect a few other factors. Factor (F10) can be considered the 'most influencing' factor as it has the highest relation with other factors.
- Quadrant IV: Includes the 'effect' factors with high prominence and low relation. This quadrant comprises three factors; *Organisational readiness* (F9), *Communication behaviour of an organisation* (F2), and *Top management support* (F8). These factors are influenced by other factors and represent a core cluster to must be managed. However, they cannot be addressed directly.

Based on the mentioned results, the Intention of BIM in Pre-2011 period occurred when *BIM characteristics* [i.e., *Relative advantage of BIM* (F6) and *Observability of BIM benefits* (F3)] stimulated specific *Internal Environment characteristics* [i.e., *Organisational readiness* (F9), and *Communication behaviour of an organisation* (F2)] after organisations had become more knowledgeable and aware of BIM. Together these factors, with the contribution from other independent factors [i.e., *Coercive pressures* (F10), *Organisational culture* (F7), and *Compatibility of BIM* (F4)], attracted the attention of the organisations' decision-making units (i.e., decision-makers), and invited more executive support in the organisations [i.e., *Top management support* (F8)] to formulate a favourable attitude (i.e., Intention) towards BIM adoption (Figure 8.9).

As the UK Government BIM/Construction strategy had not been yet announced in the Pre-2011 period, therefore the coercive pressures in this period were mostly informal mandate/pressures by the parent companies, partners, and clients to promote the adoption of BIM as a new innovation to shift the conventional workflows and processes in the construction industry mainstream.

Table 8.10 The De-Fuzzified total relation matrix T of the Intention Stage for the Pre-2011 Period

Factors	F2	F3	F4	F6	F7	F8	F9	F10
F2. Communication behaviour	0	0.191	0.180	0.179	0.167	0.184	0.189	0.131
F3. Observability of BIM	0.188	0	0.188	0.194	0.147	0.230	0.152	0.126
F4. Compatibility of BIM	0.164	0.169	0	0.167	0.142	0.203	0.151	0.125
F6. Relative advantage of BIM	0.214	0.192	0.208	0	0.161	0.223	0.173	0.134
F7. Organisational culture	0.185	0.135	0.128	0.165	0	0.195	0.169	0.125
F8. Top management support	0.194	0.149	0.128	0.132	0.164	0	0.176	0.124
F9. Organisational readiness	0.188	0.167	0.155	0.196	0.145	0.192	0	0.124
F10. Coercive pressures	0.187	0.137	0.130	0.154	0.162	0.228	0.169	0

Table 8.11 The F-DEMATEL results of the Intention Stage for the Pre-2011 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F2. Communication behaviour	1.282	1.382	2.665	3	-0.100	Effect
F3. Observability of BIM	1.284	1.199	2.483	2	0.085	Cause
F4. Compatibility of BIM	1.178	1.174	2.352	6	0.004	Cause
F6. Relative advantage of BIM	1.367	1.248	2.615	1	0.119	Cause
F7. Organisational culture	1.156	1.142	2.299	7	0.014	Cause
F8. Top management support	1.128	1.516	2.644	8	-0.388	Effect
F9. Organisational readiness	1.226	1.237	2.463	4	-0.011	Effect
F10. Coercive pressures	1.219	0.942	2.162	5	0.277	Cause

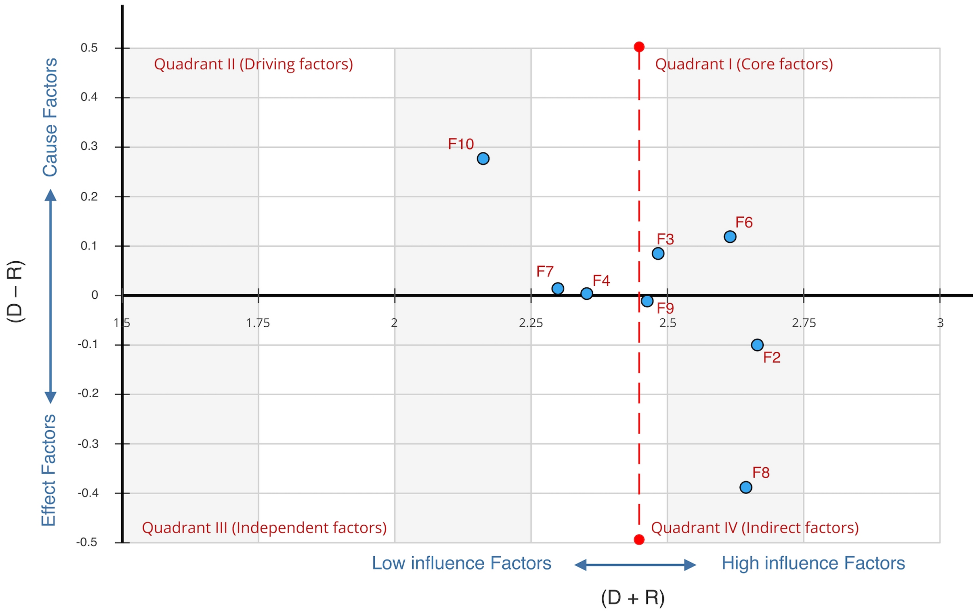


Figure 8.10 Causal diagram (Digraph) of the Intention Stage for the Pre-2011 Period

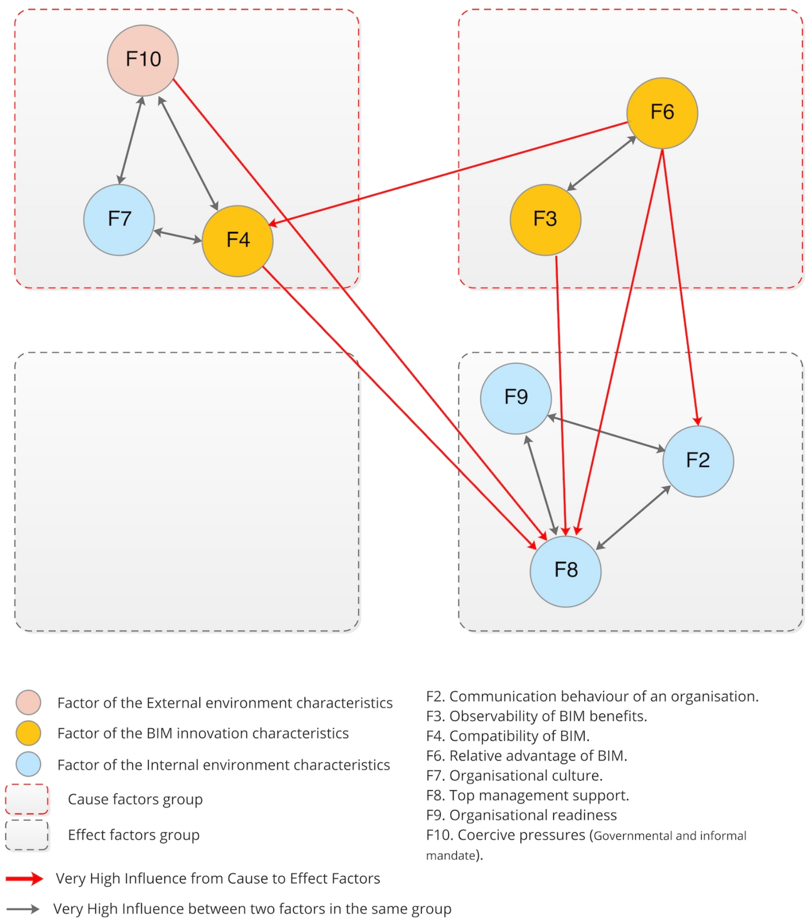


Figure 8.9 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Intention Stage for the Pre-2011 Period

8.3.3.5 The F-DEMATEL model of the Intention Stage for the 2011-2016 Period

In this F-DEMATEL model, six factors were included, *Communication behaviour of an organisation* (F2), *Observability of BIM benefits* (F3), *Compatibility of BIM* (F4), *Relative advantage of BIM* (F6), *Organisational culture* (F7), and *Organisational readiness* (F9). The results of conducting the F-DEMATEL method have revealed two groups of factors (Table 8.12 and Table 8.13): the *cause group*, which comprises the following factors ranked in a descending order: *Relative advantage of BIM* (F6), *Communication behaviour of an organisation, Organisational readiness* (F9), and *Organisational culture* (F7). The *effect group* includes only two factors: *Observability of BIM benefits* (F3) and *Compatibility of BIM* (F4). The threshold value of this model is 5.522 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.11 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), and *Communication behaviour of an organisation* (F2), which are the cause factors influencing most other factors and can unlock them in a BIM adoption strategy. In this cluster, (F6) is the 'most important' factor as it has the highest centrality degree.
- Quadrant II: Includes the 'Driving' factors with low prominence and high relation. These factors are *Organisational readiness* (F9) and *Organisational culture* (F7), which only affect a few other factors. Factor (F9) can be considered the 'most influencing' factor as it has the highest relation with other factors.
- Quadrant III: It contains only one 'effect' factor, *Compatibility of BIM* (F4), which is affected by other factors.
- Quadrant IV: Includes only one 'effect' factor with high prominence and low relation [i.e., *Observability of BIM benefits* (F3)]. This factor is influenced by other factors and represents the core factor that must be managed.

The 'Intention' to adopt BIM in the 2011-2016 period occurred when specific Internal Environment characteristic [i.e., *Organisational readiness* (F9) and *Organisational culture* (F7)] independently stimulated a particular BIM characteristic and Internal Environment characteristic [i.e., *Relative advantage of BIM* (F6) and *Communication behaviour of an organisation* (F2)] after organisations had become more knowledgeable and aware of BIM. It occurs when the potential adopters' (i.e., organisations) *Organisational readiness* (F9) and shared norms, beliefs, and traditions (F7), held by the members of these organisational practices, contribute to stimulating the appreciation of the potential benefits obtained from adopting BIM (F6); and increasing the openness and engagement of these organisation with social groupings and networks interested in BIM adoption and promotion (F2). These factors (F6, F2, F9 and F7) will, in turn, affect in demonstrating visible and tangible results of successful BIM adoption examples of other organisations (F3); and finally, clarifying how can BIM be aligned with the potential adopter's previous experiences and current needs and values (F4), which formulates a favourable attitude (i.e., Intention) towards BIM adoption (Figure 8.12).

Table 8.12 The De-Fuzzified total relation matrix T of the Intention Stage for the 2011-2016 Period

Factors	F2	F3	F4	F6	F7	F9
F2. Communication behaviour	0	0.189	0.182	0.177	0.156	0.178
F3. Observability of BIM	0.173	0	0.185	0.190	0.132	0.137
F4. Compatibility of BIM	0.149	0.161	0	0.161	0.128	0.137
F6. Relative advantage of BIM	0.201	0.189	0.208	0	0.147	0.160
F7. Organisational culture	0.171	0.127	0.124	0.159	0	0.154
F9. Organisational readiness	0.176	0.163	0.153	0.195	0.134	0

Table 8.13 The F-DEMATEL results of the Intention Stage for the 2011-2016 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F2. Communication behaviour	0.942	0.929	1.872	2	0.013	Cause
F3. Observability of BIM	0.874	0.887	1.761	4	-0.013	Effect
F4. Compatibility of BIM	0.791	0.907	1.698	5	-0.116	Effect
F6. Relative advantage of BIM	0.964	0.942	1.907	1	0.022	Cause
F7. Organisational culture	0.788	0.748	1.536	6	0.040	Cause
F9. Organisational readiness	0.878	0.822	1.700	3	0.055	Cause

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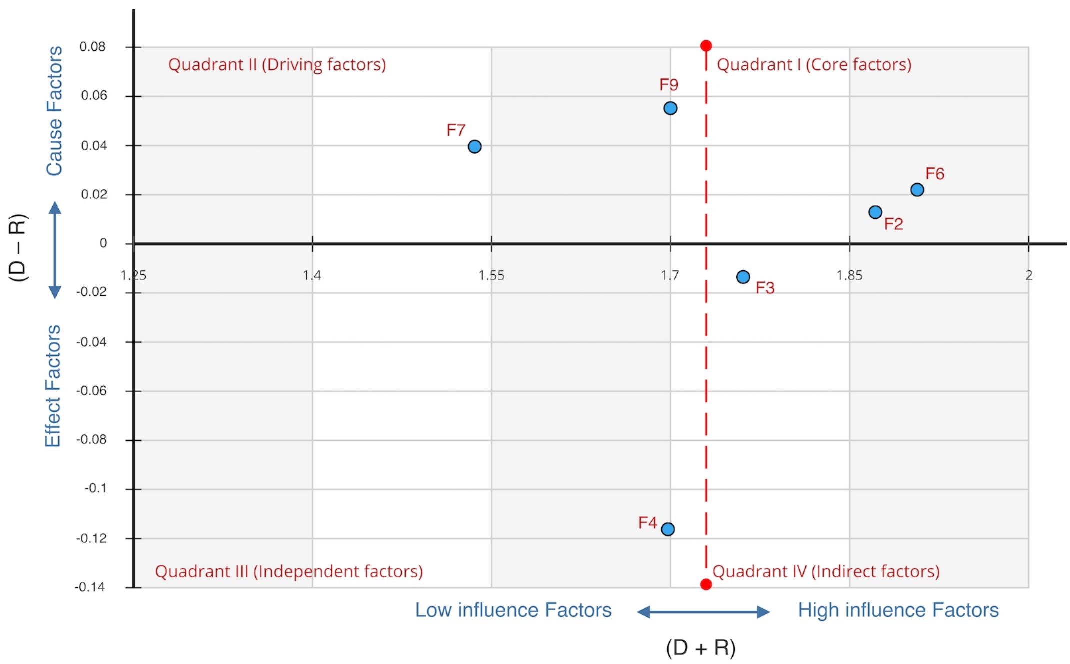


Figure 8.11 Causal diagram (Digraph) of the Intention Stage for the 2011-2016 Period

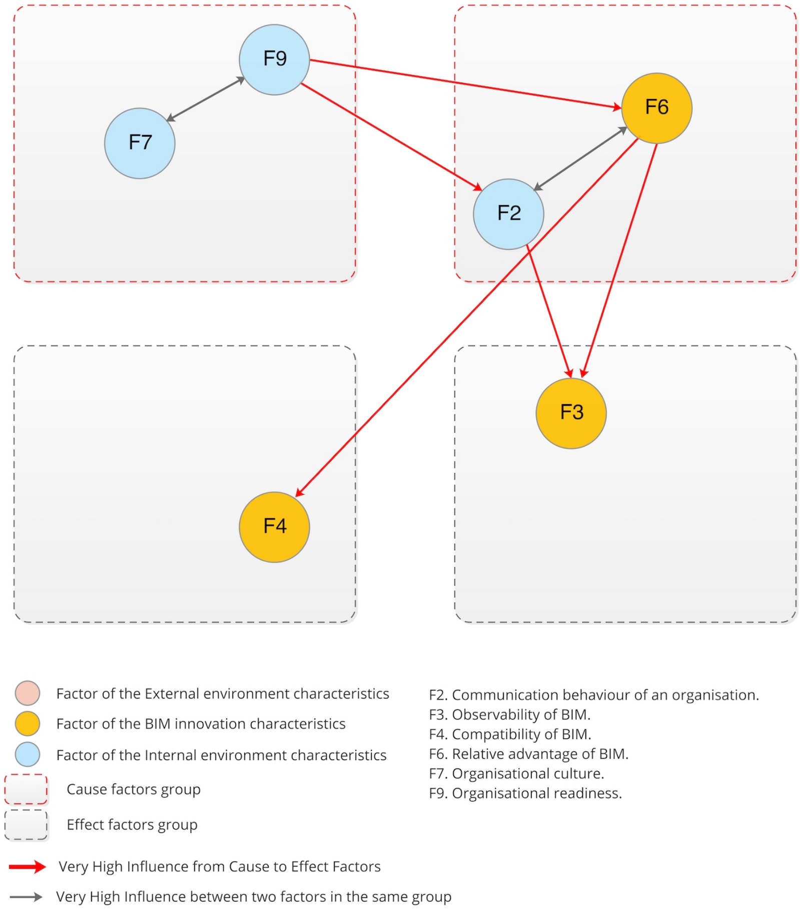


Figure 8.12 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Intention Stage for the 2011-2016 Period

8.3.3.6 The F-DEMATEL model of the Intention Stage for the Post-2016 Period

Two factors, *Compatibility of BIM* (F4), and *Coercive pressures* (Governmental mandate, informal mandate) (F10), were included in the F-DEMATEL model of the Intention Stage for the Post-2016 period. The results (Table 8.14 and Table 8.15) of conducting the FDEMATEL method have revealed that (F4) is the cause factor, and (F10) is the effect factor (Figure 8.13). Due to the symmetrical location/projection of both factor (F4) between quadrant I and quadrant II, and factor (F10) between quadrant III and quadrant IV; and the mutual influence, it allows each of these factors to influence each other regardless their reciprocal influence independently.

The 'Intention' to adopt BIM in the Post-2016 period occurred when the BIM mandate (F10) affected the perception of alignment between the potential adopter's previous experiences and current needs and values (F4). It may occur when either: (1) the external pressures (i.e., exerted by influential partners, clients, and government pressures) encourage the general attitude of the potential adopters (i.e., organisations) to formulate a favourable attitude (i.e., Intention) towards BIM adoption; or (2) the needs and values of these organisations facilitate the influence of the external pressures to accelerate the intention process (Figure 8.14).

Table 8.14 The De-Fuzzified total relation matrix T of the Intention Stage for the Post-2016 Period

Factors	F2	F10
F4. Compatibility of BIM	0	4.280
F10. Coercive pressures	3.764	0

Table 8.15 The F-DEMATEL results of the Intention Stage for the Post-2016 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F4. Compatibility of BIM	5.780	5.264	11.044	1	0.515	Cause
F10. Coercive pressures	5.264	5.780	11.044	2	-0.515	Effect

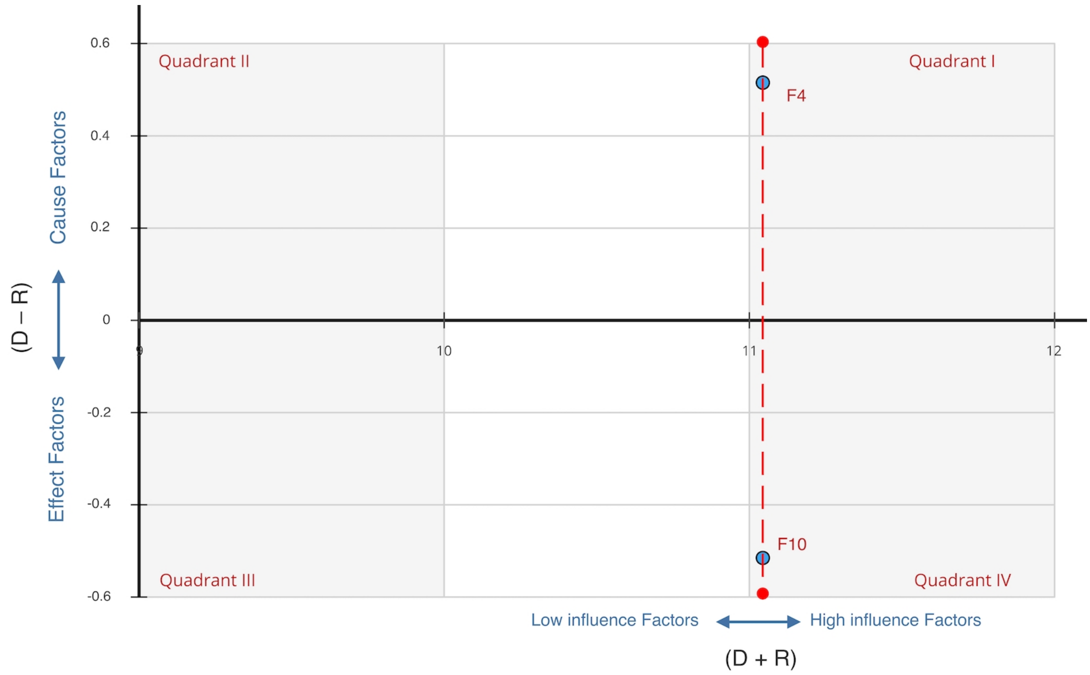


Figure 8.13 Causal diagram (Digraph) of the Intention Stage for the Post-2016 Period

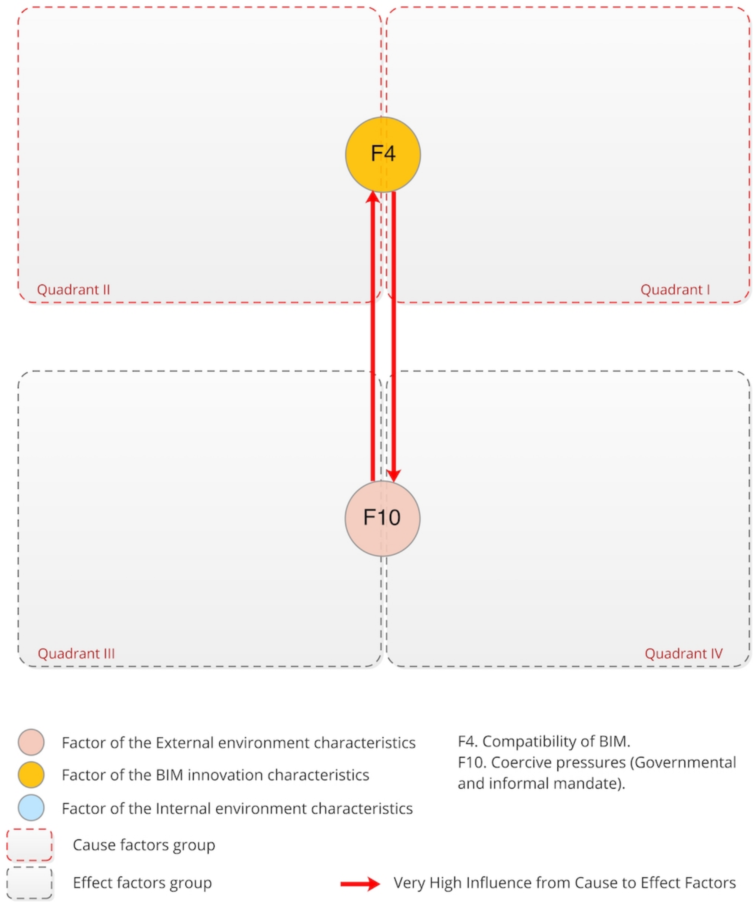


Figure 8.14 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Intention Stage for the Post-2016 Period

8.3.3.7 The F-DEMATEL model of the Decision Stage for the Pre-2011 Period

In this F-DEMATEL model, five factors were included, *Communication behaviour of an organisation* (F2), *Relative advantage of BIM* (F6), *Top management support* (F8), *Organisational readiness* (F9), and *Coercive pressures (Governmental mandate, informal mandate)* (F10). The results of conducting the F-DEMATEL method have revealed two groups of factors (Table 8.16 and Table 8.17): the *cause group*, which comprises the following factors ranked in descending order: *Coercive pressures (Governmental mandate, informal mandate)* (F10) and *Relative advantage of BIM* (F6). The *effect group* includes: *Top management support* (F8), *Communication behaviour of an organisation* (F2), and *Organisational readiness* (F9). The threshold value of this model is 0.289 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.16 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant II: It contains two 'Driving' factors with low prominence and high relation. These factors are *Coercive pressures* (F10), and *Relative advantage of BIM* (F6), which affect all other factors. Factor (F10) can be considered the 'most influencing' factor as it has the highest relation with other factors.
- Quadrant IV: Includes the 'effect' factors with high prominence and low relation. This quadrant comprises three factors; *Organisational readiness* (F9), *Communication behaviour of an organisation* (F2), and *Top management support* (F8). These factors influenced by other factors and represent a core cluster to must be managed. However, they cannot be addressed directly.

Based on the mentioned results, the 'Decision to adopt BIM' in Pre-2011 period made when a specific *External Environment characteristic* [i.e., *Coercive pressures* (F10)] and a BIM *characteristic* [i.e., *Relative advantage of BIM* (F6)] independently stimulated particular *Internal Environment characteristic* [i.e., *Organisational readiness* (F9), *Communication behaviour of an organisation* (F2), and *Top management support* (F8)] after organisations had formulated a favourable attitude towards BIM adoption. These factors (F10 and F6) psychologically and behaviourally influenced the organisation members preparation to adopt and implement BIM, their mutual determination to perform the change, and their mutual faith in their aggregate capacity to achieve the change [i.e., *Organisational readiness* (F9)]. At the same time, this increased the openness and engagement of an organisation with social groupings and networks interested in BIM adoption and promotion (F2) and encouraged the organisations' decision-making units (i.e., decision-makers), and the executive support in the organisations [i.e., *Top management support* (F8)] to facilitate making the decision to adopt BIM (Figure 8.15).

As at the Intention Stage in the same period, the UK Government BIM/Construction strategy had not been yet announced in the Pre-2011 period, therefore the coercive pressures in this period were mostly informal mandate/pressures by the parent companies, partners, and clients to promote the adoption of BIM as a new innovation to shift the conventional workflows and processes in the construction industry mainstream.

Table 8.16 The De-Fuzzified total relation matrix T of the Decision Stage for the Pre-2011 Period

Factors	F2	F6	F8	F9	F10
F2. Communication behaviour	0	0.323	0.332	0.358	0.244
F6. Relative advantage of BIM	0.406	0	0.407	0.329	0.250
F8. Top management support	0.382	0.248	0	0.350	0.242
F9. Organisational readiness	0.370	0.373	0.364	0	0.241
F10. Coercive pressures	0.380	0.301	0.449	0.347	0

Table 8.17 The F-DEMATEL results of the Decision Stage for the Pre-2011 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F2. Communication behaviour	1.370	1.650	3.020	4	-0.281	Effect
F6. Relative advantage of BIM	1.499	1.352	2.850	2	0.147	Cause
F8. Top management support	1.331	1.661	2.992	5	-0.330	Effect
F9. Organisational readiness	1.458	1.494	2.952	3	-0.036	Effect
F10. Coercive pressures	1.577	1.078	2.654	1	0.499	Cause

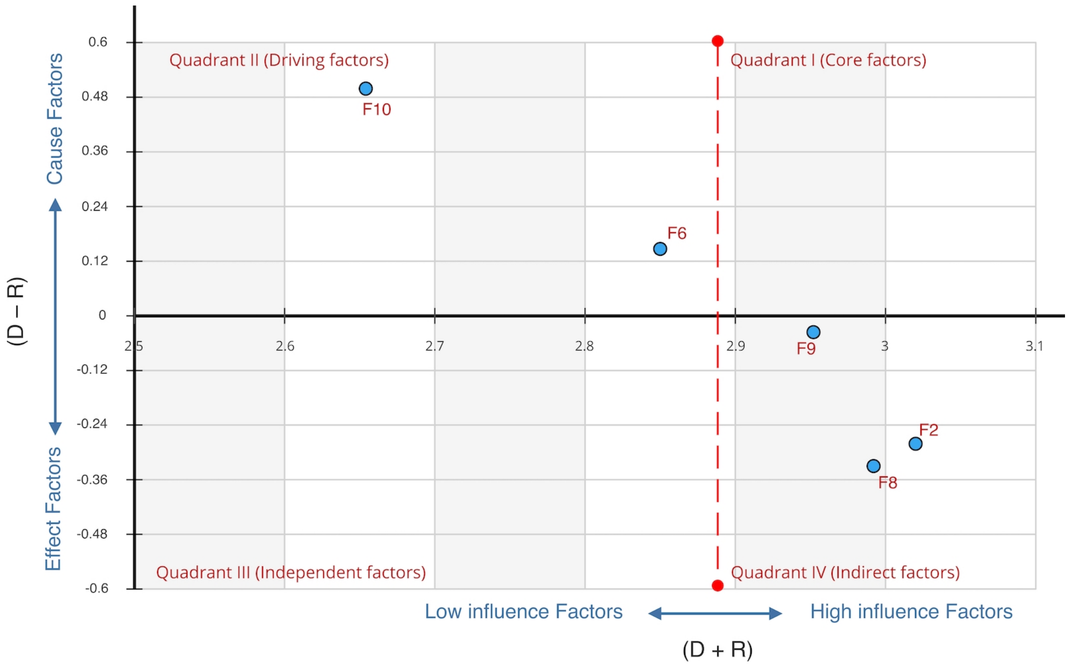


Figure 8.16 Causal diagram (Digraph) of the Decision Stage for the Pre-2011 Period

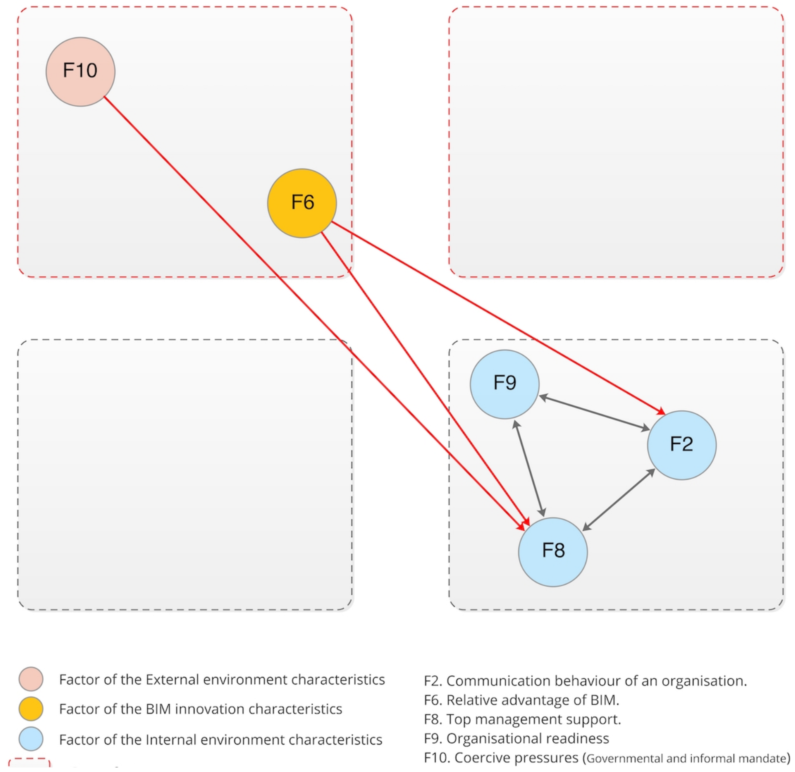


Figure 8.15 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Decision Stage for the Pre-2011 Period

8.3.3.8 The F-DEMATEL model of the Decision Stage for the 2011-2016 Period

Five factors, *Communication behaviour of an organisation* (F2), *Compatibility of BIM* (F4), *Relative advantage of BIM* (F6), *Organisational readiness* (F9), and *Organisation size* (F11) were included in the F-DEMATEL model for the 2011-2016 period. The results of conducting the F-DEMATEL method have revealed two groups of factors (Table 8.18 and Table 8.19): the *cause group*, comprises the following factors ranked in descending order: *Organisation size* (F11), *Organisational readiness* (F9), and *Relative advantage of BIM* (F6). The *effect group* includes: *Compatibility of BIM* (F4) and *Communication behaviour of an organisation* (F2). The threshold value of this model is 0.244 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.18 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), and *Organisational readiness* (F9), which are the cause factors influencing most other factors and can unlock them in a BIM adoption strategy. In this cluster, (F6) is the 'most important' factor as it has the highest centrality degree.
- Quadrant II: Only one 'Driving' factor [i.e., *Organisation size* (F11)] is included in this quadrant. This factor mainly affects *Communication behaviour of an organisation* (F2).
- Quadrant IV: Includes the 'effect' factors with high prominence and low relation. This quadrant comprises two factors; *Compatibility of BIM* (F4), and *Communication behaviour of an organisation* (F2). These factors are influenced by other factors and represent a core cluster to must be managed. However, they cannot be addressed directly.

The 'Decision to adopt BIM' in Pre-2011 period made when a specific BIM *characteristic* [i.e., *Relative advantage of BIM* (F6)] and *Internal Environment characteristic* [i.e., *Organisational readiness* (F9)] stimulated a specific *Internal*

Environment characteristic [i.e., *Communication behaviour of an organisation* (F2)] after organisations had formulated a favourable attitude towards BIM adoption. These factors (F6 and F9), simultaneously with an independent factor [i.e., *Organisation size* (F11)], improved the openness and engagement of organisations with social groupings and networks interested in BIM adoption and promotion (F2) and clarified how can BIM be aligned with the potential adopter's previous experiences and current needs and values (F4). Consequently, this facilitated making the decision to adopt BIM.

Organisation size (F11), as an independent factor, has an influence on all other factors. It can be considered to measure how various factors influencing each other according to the different sizes of organisations (i.e., micro, small, medium, and large). (Figure 8.17).

Table 8.18 The De-Fuzzified total relation matrix T of the Decision Stage for the 2011-2016 Period

Factors	F2	F4	F6	F9	F11
F2. Communication behaviour	0	0.315	0.308	0.329	0.161
F4. Compatibility of BIM	0.283	0	0.294	0.259	0.149
F6. Relative advantage of BIM	0.378	0.392	0	0.301	0.156
F9. Organisational readiness	0.342	0.300	0.365	0	0.173
F11. Organisation size	0.331	0.267	0.237	0.257	0

Table 8.19 The F-DEMATEL results of the Decision Stage for the 2011-2016 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F2. Communication behaviour	1.219	1.439	2.658	3	-0.221	Effect
F4. Compatibility of BIM	1.087	1.373	2.460	5	-0.286	Effect
F6. Relative advantage of BIM	1.333	1.310	2.642	1	0.023	Cause
F9. Organisational readiness	1.282	1.249	2.531	2	0.032	Cause
F11. Organisation size	1.171	0.719	1.891	4	0.452	Cause

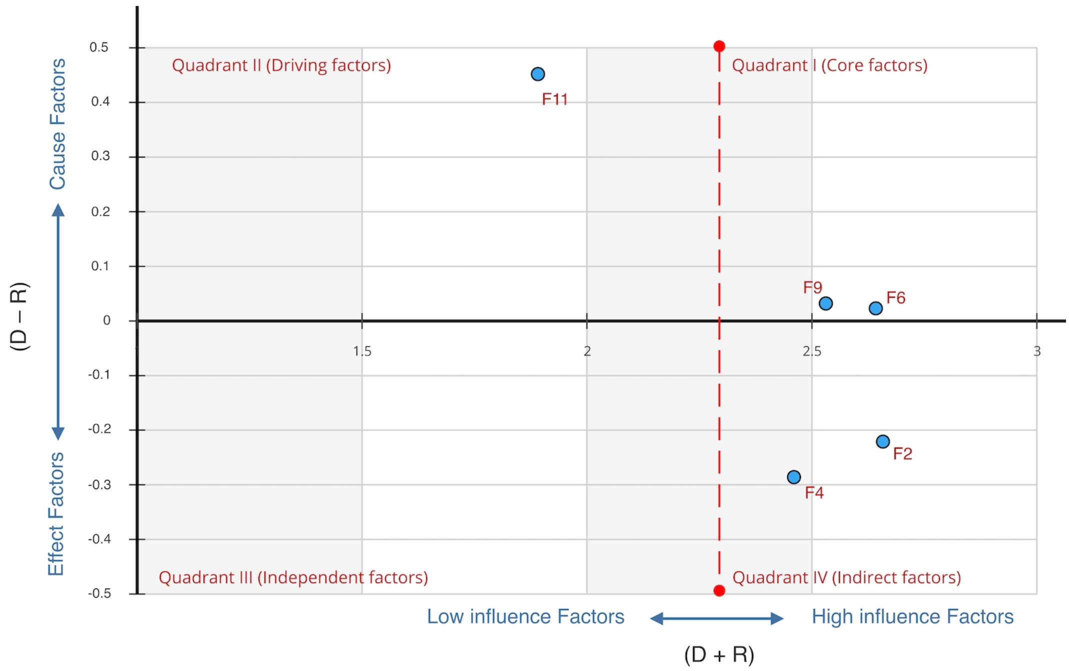


Figure 8.18 Causal diagram (Digraph) of the Decision Stage for the 2011-2016 Period

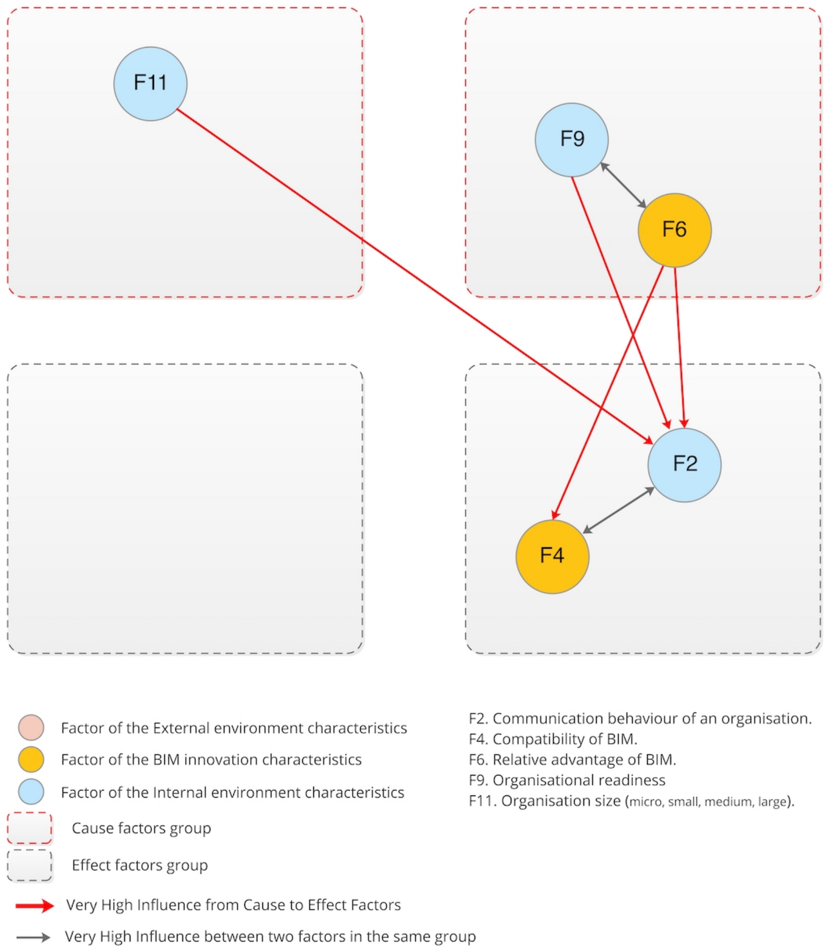


Figure 8.17 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Decision Stage for the 2011-2016 Period

8.3.3.9 The F-DEMATEL model of the Decision Stage for the Post-2016 Period

In this F-DEMATEL model, five factors were included, *Compatibility of BIM* (F4), *Relative advantage of BIM* (F6), *Top management support* (F8), *Organisational readiness* (F9), and *Coercive pressures (Governmental mandate, informal mandate)* (F10). The results of conducting the F-DEMATEL method have revealed two groups of factors (Table 8.20 and Table 8.21): the *cause group*, comprises the following factors ranked in descending order: *Coercive pressures (Governmental mandate, informal mandate)* (F10), *Relative advantage of BIM* (F6), *Compatibility of BIM* (F4), and *Organisational readiness* (F9). The *effect group* includes only one factor: *Top management support* (F8). The threshold value of this model is 0.180 to exclude the weak influence of interrelationships among the constructs/factors. Figure 8.20 shows the causal diagram (Impact-digraph) where the factors of both the cause and effect groups are distributed into their pertinent quadrant as follows:

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), and *Organisational readiness* (F9), which are the cause factors influencing most other factors and can unlock them in a BIM adoption strategy. In this cluster, (F6) is the 'most important' factor as it has the highest centrality degree.
- Quadrant II: Includes the 'Driving' factors with low prominence and high relation. These factors are *Coercive pressures* (F10), and *Compatibility of BIM* (F4), which only affect a few other factors. Factor (F10) can be considered the 'most influencing' factor as it has the highest relation with other factors.
- Quadrant IV: Includes only one 'effect' factor with high prominence and low relation [i.e., *Top management support* (F8)]. This factor is influenced by other factors and represents the core factor that must be managed.

The 'Decision to adopt BIM' in Pre-2011 period made when a specific BIM *characteristic* [i.e., *Relative advantage of BIM* (F6)] and *Internal Environment characteristic* [i.e., *Organisational readiness* (F9)] stimulated a particular *Internal Environment characteristic* [i.e., *Top management support* (F8)] after organisations had formulated a favourable attitude towards BIM adoption. Together these factors (F6 and F9), with the contribution from other independent factors [i.e., *Coercive pressures* (F10), and *Compatibility of BIM* (F4)], encouraged the organisations' decision-making units (i.e., decision-makers), and the executive support in the organisations [i.e., *Top management support* (F8)] to facilitate making the decision to adopt BIM (Figure 8.19).

Table 8.20 The De-Fuzzified total relation matrix T of the Decision Stage for the Post-2016 Period

Factors	F4	F6	F8	F9	F10
F4. Compatibility of BIM	0	0.208	0.263	0.190	0.160
F6. Relative advantage of BIM	0.260	0	0.285	0.216	0.168
F8. Top management support	0.151	0.155	0	0.218	0.153
F9. Organisational readiness	0.192	0.247	0.248	0	0.158
F10. Coercive pressures	0.160	0.190	0.299	0.216	0

Table 8.21 The F-DEMATEL results of the Decision Stage for the Post-2016 Period

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F4. Compatibility of BIM	0.891	0.833	1.724	4	0.058	Cause
F6. Relative advantage of BIM	1.002	0.874	1.876	1	0.129	Cause
F8. Top management support	0.750	1.169	1.919	5	-0.419	Effect
F9. Organisational readiness	0.917	0.913	1.830	3	0.004	Cause
F10. Coercive pressures	0.933	0.705	1.638	2	0.228	Cause

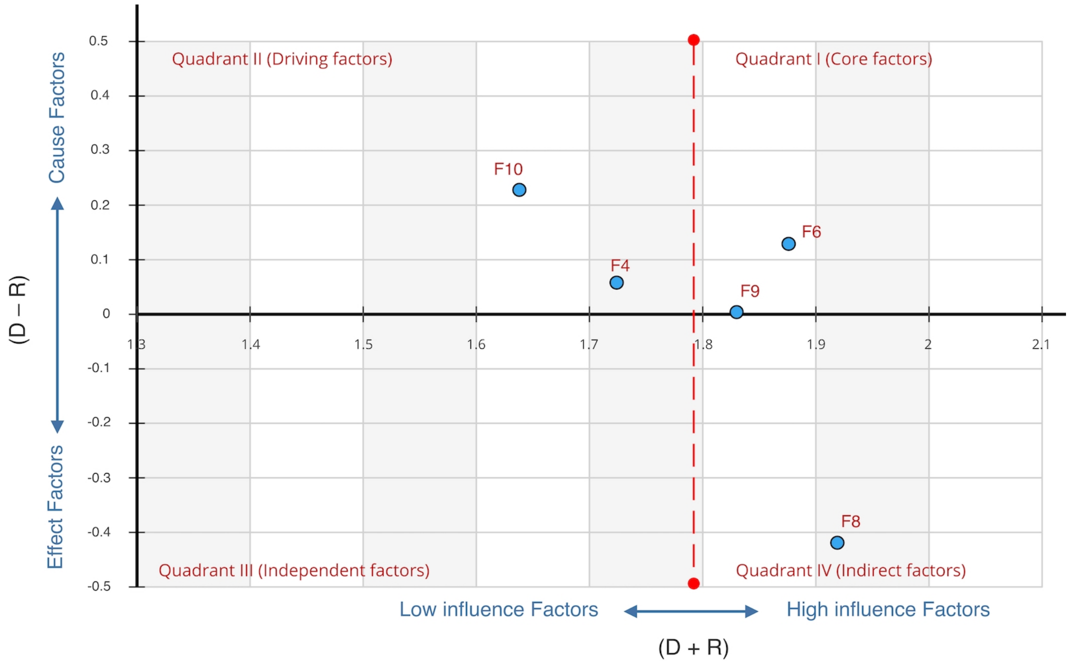


Figure 8.20 Causal diagram (Digraph) of the Decision Stage for the Post-2016 Period

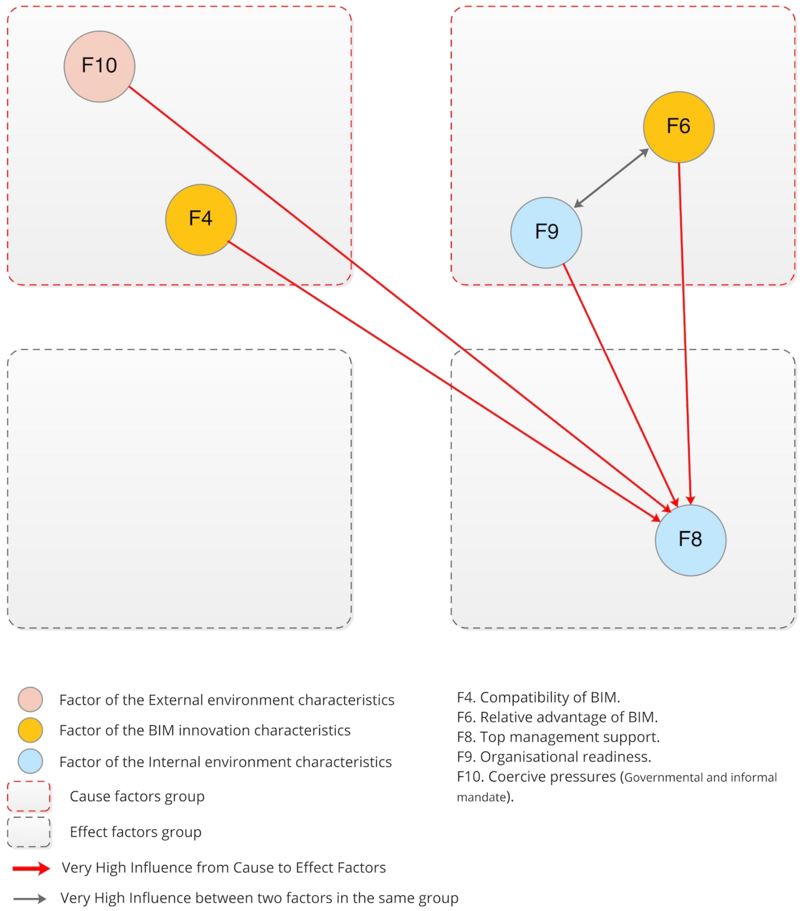


Figure 8.19 Impact Relation Map depicts the cause and effect relationships and interdependencies of the Decision Stage for the Post-2016 Period

8.3.4 Summary findings of the Eight E-DEMATEL Models

This section comprises two sub-sections that demonstrating Commonalities and Differences discussion of the influence among the F-DEMATEL Models over three time horizons and constructing the most common scenario as the representative for the UK architectural organisations BIM adoption example.

8.3.4.1 Commonalities and Differences discussion

As shown in Table 8.22, this section summarises the commonalities and differences of how the influence on each of the three stages (i.e., Awareness, Intention, and Decision) is being changed over time (i.e., Pre-2011, 2011-2016, and Post-2016).

For the **Awareness Stage**, almost similar cause factors influence the Awareness for the Pre-2011 and 2011-2016 periods. This similarity between the two periods indicates that the Government mandate did not affect the Awareness despite it was announced during the 2011-2016 period. The influence in both periods (i.e., Pre-2011 and 2011-2016) aimed at promoting the Willingness to adopt BIM (F1). For the **Intention Stage**, in general, the influence over the three time horizons of this stage focuses on inviting more executive support (F8), promoting the visibility of BIM benefits (F3), and aligning BIM with experiences and needs (F4). The Pre-2011 Period attracts the attention of the organisations' decision-making units and invited more executive support (F8). The 2011-2016 Period concerns promoting the visibility of BIM benefits and aligning BIM with experiences and needs (F4). The coercive pressures (i.e., informal pressures from clients and partners) in Pre-2011 and the combined formal and informal mandates in Post-2016 period may be the cause that made the shift of influence focus among the three periods. While for the **Decision Stage**, also almost a similar cause factors influence the Decision for over the three time horizons. In general, this influence focuses on inviting more executive support (F8), promoting Organisational communication behaviour with BIM-centric social networks (F2), and aligning BIM with experiences and needs (F4).

Table 8.22 The Commonalities and differences of the influence among the F-DEMATEL Models over three time

<table>
<tr><th>Stage</th><th>Time horizon</th><th>Influence/Cause</th><th>Effect/Aim</th><th>Commonalities/Differences</th></tr>
<tr><td rowspan="3">Awareness</td><td>Pre-2011 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6) and Observability of BIM benefits (F3)].</td><td>Internal Environment characteristic [Willingness/ intention to adopt BIM (F1)].</td><td rowspan="3">• Almost similar cause factors influence the Awareness for the Pre-2011 and 2011-2016 periods.
• The influence in both periods (i.e., Pre-2011 and 2011-2016) aimed at promoting the Willingness to adopt BIM (F1).
• This similarity between the two periods indicates that the Government mandate did not affect the Awareness despite it was announces during the 2011-2016 period.</td></tr>
<tr><td>2011-2016 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6) and Observability of BIM benefits (F3)].</td><td>Internal Environment characteristic [Willingness/ intention to adopt BIM (F1)].</td></tr>
<tr><td>Post-2016 Period</td><td colspan="2">The targeted sample did not statistically indicate any adequate representative responses of BIM Awareness in this period.</td></tr>
<tr><td rowspan="3">Intention</td><td>Pre-2011 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6) and Observability of BIM benefits (F3)].</td><td>Internal Environment characteristic [Top management support (F8)].</td><td rowspan="3">• In general, the influence over the three time horizons of this stage focuses on inviting more executive support (F8), promoting the visibility of BIM benefits (F3), and aligning BIM with experiences and needs (F4).
• Pre-2011 Period: attracts the attention of the organisations' decision-making units and invited more executive support (F8).
• 2011-2016 Period: concerns promoting the visibility of BIM benefits and aligning BIM with experiences and needs (F4).
• The influence of the coercive pressures (i.e., informal pressures from clients and partners) (F10) may be the cause that made the shift of influence focus between the two periods.</td></tr>
<tr><td>2011-2016 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6)] and Internal Environment characteristics [Organisational readiness (F9)].</td><td>BIM characteristics [Compatibility of BIM (F4) and Observability of BIM benefits (F3)].</td></tr>
<tr><td>Post-2016 Period</td><td colspan="2">mutual influence of external pressures [Coercive pressures (F10)] and BIM characteristics [Compatibility of BIM (F4)]</td></tr>
<tr><td rowspan="3">Decision</td><td>Pre-2011 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6) and External pressures [Coercive pressures (F10)]</td><td>Internal Environment characteristic [Top management support (F8) and Communication behaviour of an organisation (F2)]</td><td rowspan="3">• Almost similar cause factors influence the Decision for the three time horizons.
• In general, the influence over the three time horizons of this stage focuses on inviting more executive support (F8), promoting Organisational communication behaviour with BIM-centric social networks (F2), and aligning BIM with experiences and needs (F4).</td></tr>
<tr><td>2011-2016 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6)] and Internal Environment characteristics [Organisational readiness (F9)].</td><td>Internal Environment characteristic [Communication behaviour of an organisation (F2)] and BIM characteristics [Compatibility of BIM (F4)].</td></tr>
<tr><td>Post-2016 Period</td><td>Mainly influenced by BIM characteristics [Relative advantage of BIM (F6)] and Internal Environment characteristics [Organisational readiness (F9)].</td><td>Internal Environment characteristic [Top management support (F8)].</td></tr>
</table>

8.3.4.2 The representative scenario of the BIM adoption in the UK architectural sector

In this section, the most common scenarios of the BIM adoption process were constructed and selected as the representative for the UK architectural organisations BIM adoption example. This BIM adoption scenario (Scenario No. 4 of Figure 8.21) is one of a total ten possible scenarios that at least one or more of the targeted sample of organisations in the UK architectural sector have already embraced. This scenario is identified based on the year average of occurrence for each stage of the BIM adoption process (i.e., Awareness, Intention, and Decision) with a percentage of 27% of the total sample. The ten scenarios (i.e., 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10) have the following percentages 18%, 7%, 1%, 27%, 7%, 1%, 25%, 10%, 3%, and 1%, respectively. According to the statistical analysis results, the year average of Awareness Stage occurred in 2010 (i.e., Pre-2011 Period), the year average of Intention Stage occurred in 2012 (i.e., 2011-2016 Period), and year average of Decision Stage occurred in 2013 (i.e., 2011-2016 Period).

These ten BIM adoption scenarios were obtained from conducting the F-DEMATEL method, which introduced eight F-DEMATEL models (i.e., excluding the Awareness Stage for the Post-2016 Period as the targeted sample is not statistically adequate) of the three stages of BIM adoption process while considering the time horizon of the UK BIM Strategy. Figure 8.21 shows the exhaustive list of ten scenarios of BIM adoption process in the UK architectural sector.

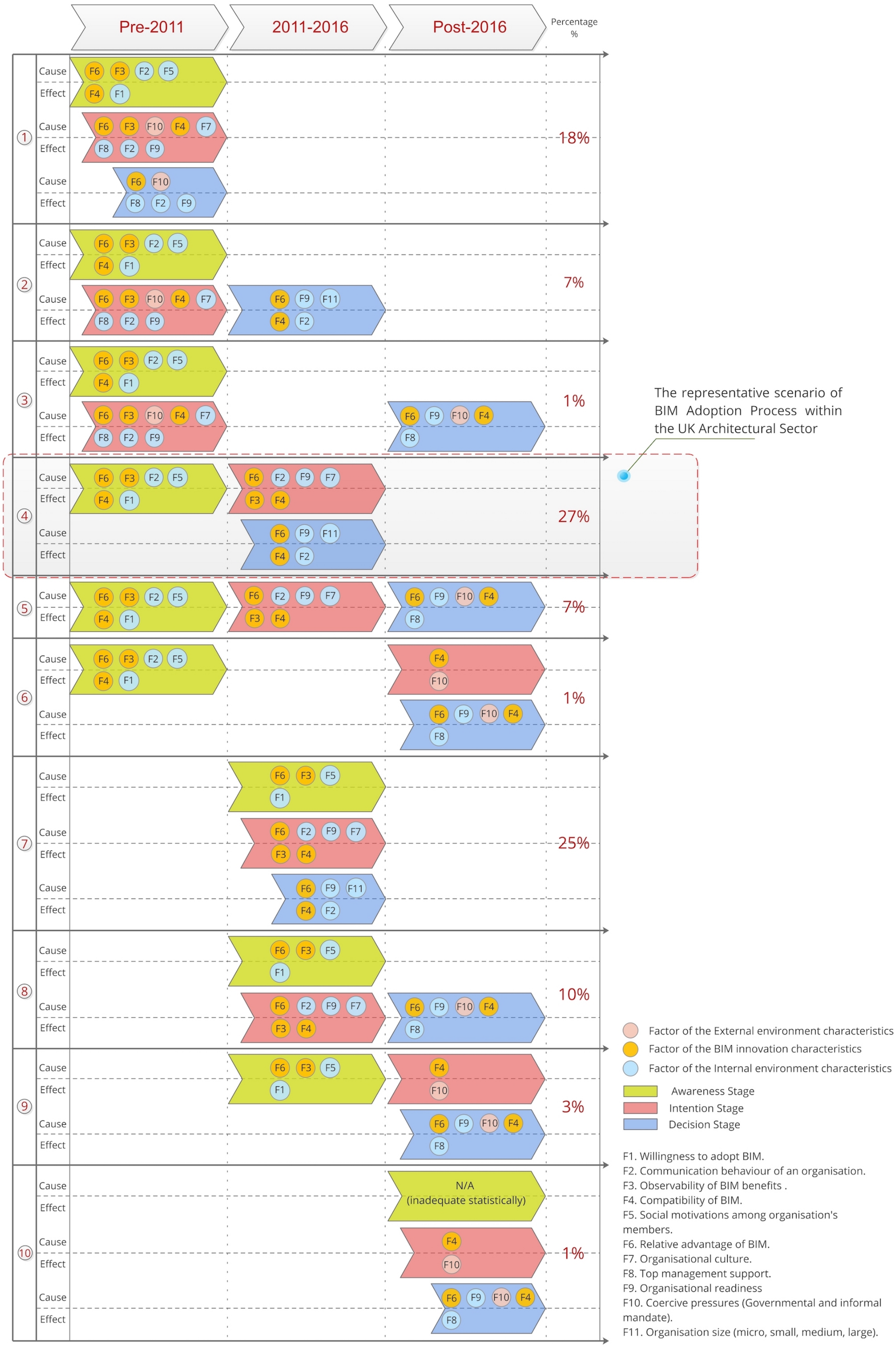


Figure 8.21 An Exhaustive list of the possible ten scenarios of BIM adoption process in the UK architectural sector

8.4 Developing a Systems Thinking Model of BIM Adoption Process

Having identified the impact of causal relationships amongst the factors influencing BIM adoption process, this section employs a systems thinking approach to develop a system dynamic model. This model allows to further analyse and understand the interrelationships (Yeon et al., 2006) among the factors of BIM adoption process, and in turn, aims at answering the fundamental question on how intra-organisation BIM adoption and diffusion occur and how the organisations make the decision to adopt BIM. To develop this systems thinking model, a Causal-Loop Diagramming (CLD) will be utilised to illustrate these chain of causal relationships among the factors affecting the BIM adoption process (i.e., system).

The CLD is based on the key variables of the systems (i.e., factors) where the interrelationships among these factors are critical in the system interpretation since they describe the systems' dynamics (Suprun et al., 2016). It is a tool that forms a complicated system by mapping a set of interactions among the systems' factors. The CLD delivers an additional visual comprehension of the current systemic relations among the system's components (Suprun et al., 2016; Richardson, 1986).

Constructing a causal-loop diagram (CLD) entails combining and integrating certain sets of input information (Suprun et al., 2016). Hence, the findings of both the 'F-DEMATEL method' and the 'statistical analysis' were incorporated to illustrate and depict the causal feedback loops. For the F-DEMATEL, the causal relationships (maps and diagraphs) among the factors influencing BIM adoption process were included. While for the statistical analysis, the 11 most influencing factors resulted from the Ordinal Logistic Regression, and a set of 31 pairs of strong relationships (i.e., 28 strong positive relationships and 3 negative ones which represent the coexistence relationships among these factors) that were statistically significant and resulted from correlation analysis (i.e., while considering the three stages of BIM adoption process, and the time horizon of the UK Government Construction/BIM Strategy) were also included.

First, the requirements for developing the CLDs of both the whole BIM Adoption Process (time-independent), and the individual BIM Adoption stages (time-dependent) are identified. The most common scenario (Scenario No. 4 of Figure 8.21) is considered – as the representative for the UK architectural organisations BIM adoption – for the time-dependent example. Second, the system's variables (i.e., factors) and their causal feedback loops were identified based on the 'causal diagraph' and the 'impact relation map' of the selected BIM adoption scenario. The diagram may include several direct and indirect arrows that indicate the impact level among the variables which reflect direct influences and indirect influences (loops) respectively. Third, the identification of the polarity of each relationship between two variables of the system was determined based on the positive (+) and negative (-) relationships resulted from the correlation analysis. A causal arrow between two factors indicates the direction of the change between the cause-effect pair. The polarity is denoted by (+) when two interrelated factors/variables increase or decrease together, and is denoted by (-) when one of them increases and the other decreases or vice versa. Also, a CLD may include two types of feedback loops: Reinforcing (R) loop, when two factors influence each other by two opposite (+) arrows; and Balancing (B) loop, when one arrow is (+) and the other is (-) or vice versa. Some causal link arrows may have marked with two hash (||) which denote 'delay' referring to the state when the effect takes time before it comes into place.

In the following sections, two systems thinking models will be developed. The first model represents a prototype or standard model which is formed based on the F-DEMATEL of the whole system of BIM adoption process (11 factors) without considering any time horizon, while the second model represents the most common scenario (Scenario No. 4) of the BIM adoption process that was formed and selected as the representative for the UK architectural organisations BIM adoption example.

8.4.1 The Systems Thinking Model: Whole BIM Adoption Process (time-independent)

Using the F-DEMATEL and the correlation analysis outcomes, a causal loop diagram can be developed. The first diagram that will be developed considers the adoption process as a single system without differentiating between the stages and the time horizon. It focusses on the 'Decision to adopt BIM' as an outcome and aims to analyse the independencies between factor that lead to such an outcome.

The CLD model was built based on incorporating the findings of the F-DEMATEL model of the whole system of BIM adoption process (i.e., 11 factors) mentioned earlier in Section 8.3.3.1 and the correlation analysis. From the F-DEMATEL, the causal relationships among the factors (i.e., the causal diagram/digraph Figure 8.3 and the impact relation map Figure 8.3) were collectively combined in multiple links that forming feedback loops. From the correlation analysis, the resultant 31 pairs of strong relationships (i.e., 28 strong positive relationships and 3 negative ones among the 11 factors) were used to identify the polarity of the formed feedback loops.

Due to the complicated nature of interrelations among the constructs/factors of the developed system (as shown in Figure 8.22), it would be impractical and unfeasible to consider influence at all level. Hence, this study has adopted a widely used approach in the literature (e.g., Falatoonitoosi et al., 2014; López-Ospina et al., 2017; Carpitella et al., 2018) which establishes a threshold value as an exclusion criterion. This value is predefined in DEMATEL matrix of each model. This threshold is calculated as the average of all the elements in matrix T (of the DEMATEL). In this model the threshold is 0.052. However, a large number of feedback loops can be recognised in the developed CLD model according to the involved factors and their multiple links. Therefore, for readability and usefulness purpose, the CLDs will include only the main feedback loops that interpret the cause-effect relationships which are reliant on the DEMATEL results considering Quadrant I of the Impact Relation Map.

As mentioned earlier, the general aim of developing a causal loop diagram is to analyse the BIM adoption process, which is a non-linear process and complex, and to look at it as a whole system. Hence, the results and discussion will focus only on the resultant feedback loops that comprise the highest number of interrelated variables/factors within each loop. Figure 8.23 shows six reinforcing loops (i.e., positive feedbacks) that are denoted by R1, R2, R3, R4, R5, and R6. The first four loops (i.e., R1, R2, R3, R4) start with the *cause group (influencing factors)* which are Relative advantage of BIM (F6), Observability of BIM (F3), Organisational readiness (F9), and Compatibility of BIM (F4), respectively. These factors were identified in quadrants I and II in the digraph of the F-DEMATEL. The other two loops (i.e., R5, R6) also influence, through their effect factors [i.e., Willingness/ intention to adopt BIM (F1) and Social motivations among organisation's members (F5), respectively], the decision to adopt BIM. These loops illustrated as follows:

- Loop R1 (i.e., Benefits of BIM innovation) suggests that promoting organisational readiness through persuading senior managers regarding the anticipated benefits of adopting BIM (Table 8.23). This loop indicates that improving the perceived benefits obtained from adopting BIM (F6) will contribute to motivating more intention of the potential adopter to adopt BIM (F1). When such intention increases, this leads to more shared norms, beliefs, and traditions (F7) held by the members of the organisational practice. These shared features increase the motivation of the organisation's members to engage in behaviours that benefit others (e.g., stimulating knowledge exchange, and focusing on collective goals) (F5). Higher social motivations then support increased openness and engagement of the organisation with social groupings and networks interested in BIM adoption and promotion (F2). Greater communication behaviours lead to increased demonstrating visible and tangible benefits from successful BIM adoption (F3). Higher visibility of BIM benefits leads to an increase in clarifying how can BIM be aligned with the potential adopter's previous experiences and current needs and values (F4) which will trigger more executive support (F8). As a result, support from senior management collaborates to psychologically increase the organisation members preparation to adopt and implement BIM and their mutual determination to perform the change (F9). This then in turn reinforcing the perceived benefits obtained from adopting BIM (F6) (Figure 8.23).

- Loop R2 (i.e., Visibility of BIM benefits) indicates the necessity of expanding the organisation's involvement with social networks interested in adopting BIM to understand its benefits (Table 8.23). It suggests that increasing the visible and tangible benefits from successful BIM adoption (F3) leads to an increase in the perceived benefits obtained from adopting BIM (F6) which results in improving the organisation perception of BIM compatibility with experiences and needs (F4). As such compatibility increases, this leads to triggering more executive support (F8) that collaborates to psychologically increase the organisation members preparation to adopt and implement BIM and their mutual determination to perform the change (F9). This determination to perform the change then will contribute to motivating more intention of the organisation to adopt BIM (F1). When such intention increases, this leads to more shared norms, beliefs, and traditions (F7) held by the members of the organisational practice. These shared features increase the motivation of the organisation's members to engage in behaviours that benefit others (F5). Consequently, higher social motivations then support increased openness and engagement of the organisation with social groupings and networks interested in BIM adoption and promotion (F2). Greater communication behaviours, in turn, reinforcing higher visibility of BIM benefits (F3) (Figure 8.23).

- Loop R3 (i.e., Organisational readiness to perform a change) suggests that the organisation's members' mutual determination to implement a change affects senior management intention to adopt BIM (Table 8.23). This loop indicates that increasing this mutual determination (F9) will contribute to motivating more intention of the organisation to adopt BIM (F1). As such intention increases, this leads to more shared norms, beliefs, and traditions (F7) held by the members of the organisational practice. These shared features increase the motivation of the organisation's members to engage in behaviours that benefit others (F5). Higher social motivations then support increased openness and engagement of the organisation with social groupings and networks interested in BIM adoption and promotion (F2). Greater communication behaviours lead to increased revealing visible and tangible benefits from successful BIM adoption (F3). This visibility of BIM benefits leads to an increase in the perceived benefits obtained from adopting BIM (F6) which results in improving the organisation perception of BIM compatibility with experiences and needs (F4). When such compatibility increases, this leads to triggering more executive support (F8). Senior management then, in turn, reinforcing the mutual determination to perform the change (F9) (Figure 8.23).

- Loop R4 (i.e., Aligning BIM with experiences and needs) implies increasing the perceived benefits of BIM innovation by promoting its compatibility with the prior experiences and current needs (Table 8.23). In this loop, improving the organisation perception of BIM compatibility (F4) leads to triggering more executive support (F8) that psychologically contribute to increasing the organisation members preparation to adopt and implement BIM and their mutual determination to perform the change (F9). Then it leads to an increase in the perceived benefits obtained from adopting BIM (F6) which in turn reinforcing the perception of BIM compatibility (F4) (Figure 8.23).
- Loop R5 (i.e., Shared norms and beliefs among an organisation' members) suggests that improving the favourable attitude of an organisation towards BIM adoption requires sharing norms and beliefs among the members of the organisation (Table 8.23). These shared features (F7) increase the motivation of the organisation's members to engage in behaviours that benefit others (F5). Greater social motivations then support increased openness and engagement with social networks concerned in BIM adoption (F2) which increases the visible and tangible benefits from successful BIM adoption (F3). This visibility of BIM benefits leads to an increase in the perceived benefits obtained from adopting BIM (F6) that will then contribute to motivating more intention of the organisation to adopt BIM (F1). Therefore, such intention in turn increases

reinforcing the organisational culture shared norms and beliefs (F7) (Figure 8.23).

- Loop R6 (i.e., Organisational communication behaviour with BIM-centric social networks) proposes that engaging organisation' members in behaviours benefitted others (e.g., stimulating knowledge exchange, and focusing on collective goals) can be motivated by expanding the organisation's involvement with social networks interested in adopting BIM to understand its benefits (Table 8.23). Greater communication behaviours (F2) lead to increase the visible and tangible benefits from successful BIM adoption (F3) which increase the perceived benefits obtained from adopting BIM (F6). Then, this will contribute to motivating more intention of the organisation to adopt BIM (F1) that increases organisational culture shared norms and beliefs (F7). These shared features increase the motivation of the organisation's members to engage in behaviours that benefit others (F5). Higher social motivations then support increased openness and engagement of the organisation with social groupings and networks interested in BIM adoption and promotion (F2).

Therefore, these six loops, mentioned above, contribute to the organisational decision to adopt BIM through their influence on four effect factors: Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Social motivations among organisation's members (F5), and Top management support (F8). Moreover, two independent factors [i.e., Coercive pressures (Governmental mandate, informal mandate), and Organisation size (F11)] have an influence on the decision to adopt BIM through their direct influence on some of the four effect factors (i.e., F8, F5, and F1). Greater coercive pressures (F10) lead to an increase in Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), and Top management support (F8). The scale of organisation size (i.e., micro, small, medium, and large) has a disparate influence on particular factors. For example, larger organisations have more Willingness to adopt BIM, more senior management support, and less communication behaviour. Figure 8.24 shows a tree diagram that provides a simplified visualisation and analysis of model dynamics. It shows in a single direction which variables cause a particular variable to change. This representation captures the several intersections between the CLDs identified earlier. Only two levels are represented in Figure 8.24 but these could be extended to represent the whole CLD as a tree diagram. These simplified causal chains, when they are followed from the left to the right side, clearly shows how the decision to adopt BIM is made within organisations.

Table 8.23 Summary of the most important feedback loops influencing the 'decision to adopt BIM' (time-independent)

loops	Loop name	Interdependent factors	Indication
R1	Benefits of BIM innovation	Relative advantage of BIM (F6) ⟶ Willingness/ intention to adopt BIM (F1) ⟶ Organisational culture (F7) ⟶ Social motivations among organisation's members (F5) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM benefits (F3) ⟶ Compatibility of BIM (F4) ⟶ Top management support (F8) ⟶ Organisational readiness (F9) ⟶ Relative advantage of BIM (F6)	Promote the organisational readiness through persuading senior managers regarding the anticipated benefits of adopting BIM.
R2	Visibility of BIM benefits	Observability of BIM benefits (F3) ⟶ Relative advantage of BIM (F6) ⟶ Compatibility of BIM (F4) ⟶ Top management support (F8) ⟶ Organisational readiness (F9) ⟶ Willingness/ intention to adopt BIM (F1) ⟶ Organisational culture (F7) ⟶ Social motivations among organisation's members (F5) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM (F3)	The necessity of expanding the organisation's involvement with social networks interested in adopting BIM to understand its benefits.
R3	Organisational readiness to perform a change	Organisational readiness (F9) ⟶ Willingness/ intention to adopt BIM (F1) ⟶ Organisational culture (F7) ⟶ Social motivations among organisation's members (F5) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM benefits (F3) ⟶ Relative advantage of BIM (F6) ⟶ Compatibility of BIM (F4) ⟶ Top management support (F8) ⟶ Organisational readiness (F9)	Organisation's members' mutual determination to implement a change affects senior management intention to adopt BIM.
R4	Aligning BIM with experiences and needs	Compatibility of BIM (F4) ⟶ Top management support (F8) ⟶ Organisational readiness (F9) ⟶ Relative advantage of BIM (F6) ⟶ Compatibility of BIM (F4)	Increasing the perceived benefits of BIM innovation by promoting its role aligned between the prior experiences and current needs.
R5	Shared norms and beliefs among an organisation' members	Organisational culture (F7) ⟶ Social motivations among organisation's members (F5) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM benefits (F3) ⟶ Relative advantage of BIM (F6) ⟶ Willingness/ intention to adopt BIM (F1) ⟶ Organisational culture (F7)	Improving the favourable attitude of an organisation towards BIM adoption requires sharing norms and beliefs among the members of the organisation.
R6	Organisational communication behaviour with BIM-centric social networks	Communication behaviour of an organisation (F2) ⟶ Observability of BIM benefits (F3) ⟶ Relative advantage of BIM (F6) ⟶ Willingness/ intention to adopt BIM (F1) ⟶ Organisational culture (F7) ⟶ Social motivations among organisation's members (F5) ⟶ Communication behaviour of an organisation (F2)	Engaging in behaviours benefitted others (e.g., stimulating knowledge exchange, and focusing on collective goals) can be motivated by expanding the organisation's involvement with social networks interested in adopting BIM to understand its benefits.

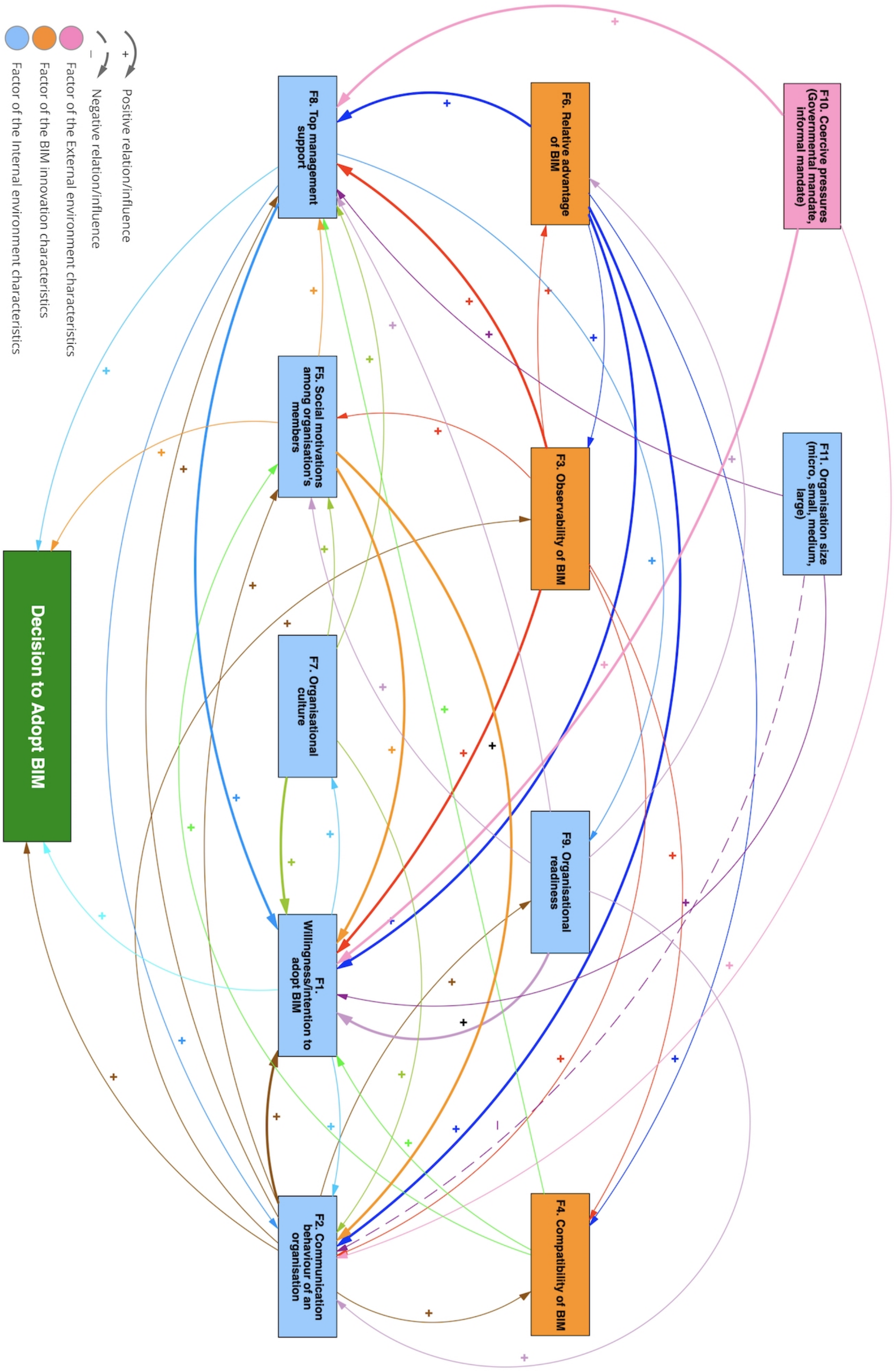


Figure 8.22 The Causal-Loop Diagram of the Systems Thinking Model of the whole system of BIM Adoption Process (11 Factors and time-independent) including all loops

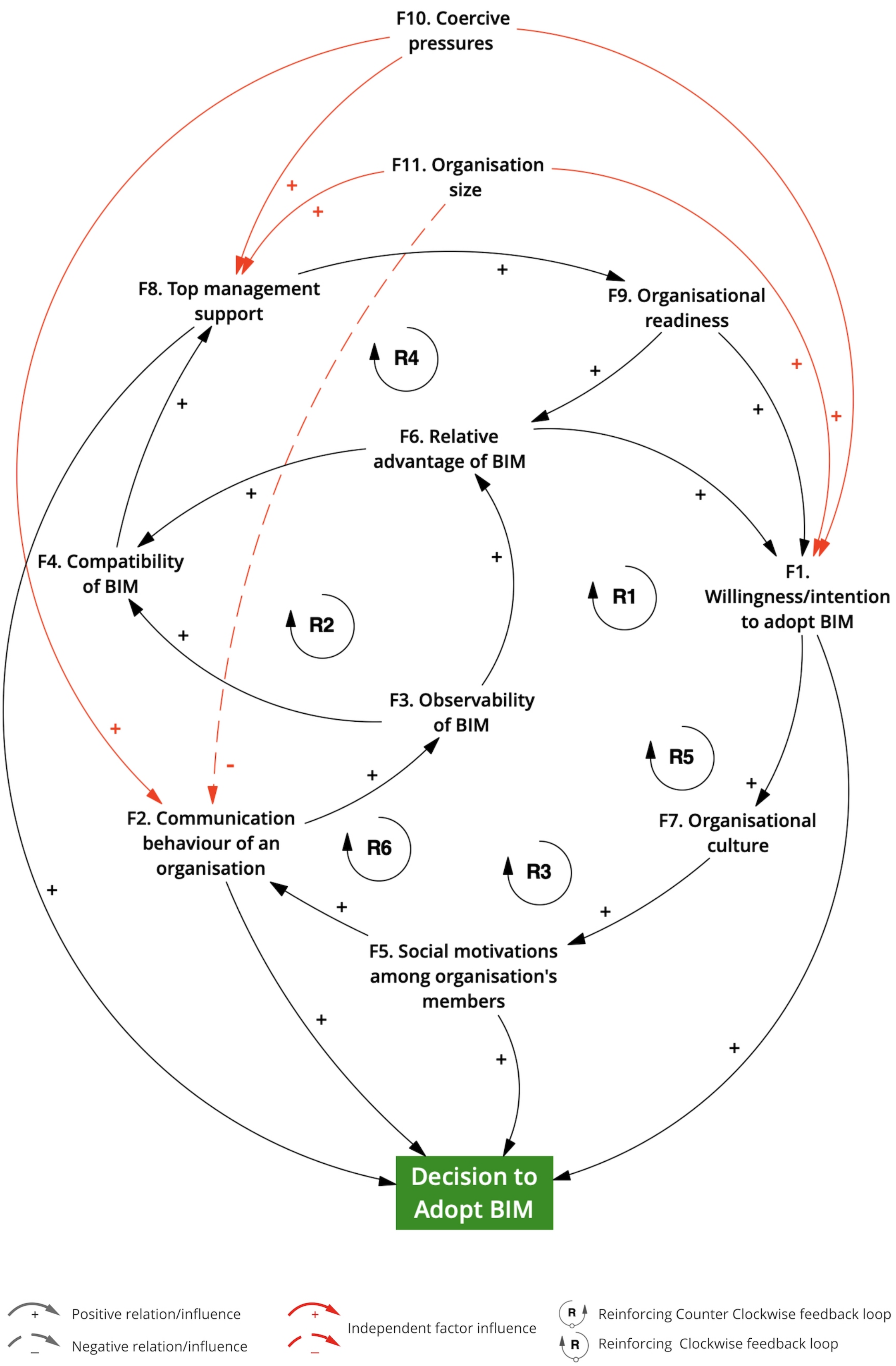


Figure 8.23 The Systems Thinking Model of Whole BIM Adoption Process (time-independent)

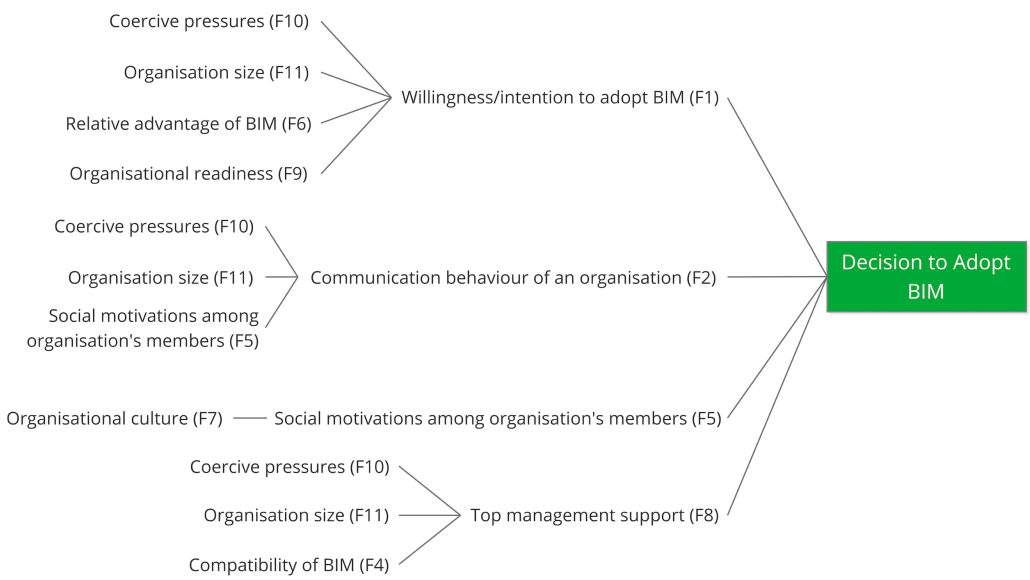


Figure 8.24 The causal relationships tree influencing the 'decision to adopt BIM' (time-independent)

8.4.2 The Systems Thinking Model: individual BIM Adoption stages (time-dependent)

This model was developed for the most common scenario (Scenario No. 4 of Figure 8.21) of the BIM adoption process in the UK architecture sector. The CLD model was built following the same approach used in the previous section. It comprises the main feedback loops that interpret the cause-effect relationships in which these loops include the maximum number of interrelated variables/factors within each loop. Three separate systems thinking models (i.e., CLDs) that represent the Awareness Stage for the Pre-2011 Period (Figure 8.25), the Intention Stage for the 2011-2016 Period (Figure 8.27), and the Decision Stage for the 2011-2016 Period (Figure 8.29), were developed. The final systems thinking model of the UK architectural organisations BIM adoption process was constructed based on combining and layering of the three CLDs of the three stages (Figure 8.31).

The CLD of the *Awareness Stage for the Pre-2011 Period* has only one direct reinforcing feedback loop [i.e., (**R1**: Visibility of BIM benefits)] (Figure 8.25). This loop indicates that the visible and tangible benefits from successful BIM adoption motivate grater communication behaviours (Table 8.24). Furthermore, together with this loop, a set of linked factors separately contribute to increasing the organisational 'BIM Awareness' through their influences on increasing the Willingness to adopt BIM (F1) and Compatibility of BIM (F4) as shown in Figure 8.26.

Regarding the CLD of the *Intention Stage for the 2011-2016* Period, it has three reinforcing feedback loops including: **R1**, **R2**, and **R3** (Figure 8.27). Loop **R1** (i.e., Benefits of BIM innovation) indicates that Promote the organisational readiness through the anticipated benefits of adopting BIM. Then, loop **R2** (i.e., Organisational communication behaviour with BIM-centric social networks) suggests that Greater communication behaviours lead to increase the visible and tangible benefits from successful BIM adoption. Loop **R3** (i.e., Organisational readiness to perform a change) implies that the organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM (Table 8.25). In addition to the three loops, a cluster of linked factors increases the influence of Compatibility of BIM (F4) and Observability of BIM benefits (F3) that in turn leads to an increase the organisational 'BIM Intention' in formulating a favourable attitude towards the decision to adopt BIM. Figure 8.28 shows the causal relationships tree influencing the 'BIM Intention Stage'.

The third CLD model is for the *Decision Stage of the 2011-2016 Period*. It also has three reinforcing feedback loops. These are **R1**, **R2**, and **R3** (Figure 8.29). Loop **R1** (i.e., Benefits of BIM innovation) suggests that the perceived benefits obtained from adopting BIM may result in improving the organisation perception of BIM compatibility with experiences and current needs. Next, loop **R2** (i.e., Organisational readiness to perform a change) proposes that the organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM. Loop **R3** (i.e., Organisational communication behaviour with BIM-centric social networks) implies that greater communication behaviours lead to increase the organisation's members' mutual determination to perform the change which is motivated by the perceived benefits and compatibility of BIM innovation (Table 8.26). Also, besides these loops, a group of linked factors causes an increase in the influence of Compatibility of BIM (F4) and Communication behaviour of an organisation (F2) which leads to increase the organisational determination towards making the decision to adopt BIM. Organisation size (F11), as an independent factor, has a negative influence – as explained earlier – on Communication behaviour (F2) (e.g., larger organisations have less communication behaviour and vice versa). Figure 8.30 shows the causal relationships tree influencing the 'BIM Decision Stage'.

Finally, the last CLD model represents the UK architectural organisations BIM adoption process which is developed based on combining of the three CLDs of the three stages. It consists of six reinforcing feedback loops denoted by **R1**, **R2**, **R3**, **R4**, **R5**, and **R6** (Figure 8.31). The first loop **R1** (i.e., Benefits of BIM innovation) proposes that the perceived benefits obtained from adopting BIM result in improving the organisation perception of BIM compatibility with experiences and current needs. Loop **R2** (i.e., Reinforcing visibility of BIM benefits) affirms that the visible and tangible benefits from successful BIM adoption motivate grater communication behaviours through a direct feedback loop. Next, loop **R3** (i.e., Visibility of BIM benefits) indicates that increasing the visibility of these benefits leads to an increase in the perceived benefits obtained from adopting BIM. Loop **R4** (i.e., Organisational communication behaviour with BIM-centric social networks) implies that greater communication behaviours lead to increase the visibility of benefits from successful BIM adoption. Then, loop **R5** (i.e., Organisational readiness to perform a change) suggests that the organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM. Finally, loop **R6** (i.e., Reinforcing organisational readiness to perform a change) confirms promoting the organisational readiness through increasing the perceived benefits obtained from adopting BIM (i.e., direct feedback loop) (Table 8.27). Together with these six loops, three individual factors [i.e., Social motivations among organisation's members (F5), Organisational culture (F7), and Organisation size (F11)] have a separate influence on the three stages of BIM adoption process through their direct influence on some of the following effect factors. These factors are: Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), and Compatibility of BIM (F4), which play a key role in facilitating (i.e., mediators) the effects of the causal feedback loops and direct influences separately on each of the three stages (Figure 8.31).

Also, two causal link arrows were included in the CLD that refer to the delay occurred when transferring from the 'Awareness Stage' to the 'Intention Stage', and from the 'Intention Stage' to the 'Decision Stage'. These delays due to the year average of Awareness of BIM occurred in 2010, the average of Intention in BIM occurred in 2012, and the average of Decision to adopt BIM occurred in 2013 which indicates two transitional gaps of time between every two consecutive stages (Figure 8.31). Figure 8.32 shows the causal relationships tree influencing the 'BIM Decision Stage' considering the relationships with the two previous stages.

Table 8.24 Summary of the most important feedback loop influencing the 'BIM Awareness Stage' for the Pre-2011 Period

loops	Loop name	Interdependent factors	Indication
R1	Visibility of BIM benefits	Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM (F3)	The visible and tangible benefits from successful BIM adoption motivate grater communication behaviours

Table 8.25 Summary of the most important feedback loop influencing the 'BIM Intention Stage' for the 2011-2016 Period

loops	Loop name	Interdependent factors	Indication
R1	Benefits of BIM innovation	Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Relative advantage of BIM (F6)	Promote the organisational readiness through the anticipated benefits of adopting BIM.
R2	Organisational communication behaviour with BIM-centric social networks	Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2)	Greater communication behaviours lead to increase the visible and tangible benefits from successful BIM adoption.
R3	Organisational readiness to perform a change	Organisational readiness (F9) ⟶ Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9)	Organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM.

Table 8.26 Summary of the most important feedback loop influencing the 'BIM Decision Stage' for the 2011-2016 Period

loops	Loop name	Interdependent factors	Indication
R1	Benefits of BIM innovation	Relative advantage of BIM (F6) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6)	The perceived benefits obtained from adopting BIM result in improving the organisation perception of BIM compatibility with experiences and current needs.
R2	Organisational readiness to perform a change	Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9)	Organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM.
R3	Organisational communication behaviour with BIM-centric social networks	Communication behaviour of an organisation (F2) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6) ⟶ Organisational readiness (F9) ⟶ Communication behaviour of an organisation (F2)	Greater communication behaviours lead to increase the organisation's members' mutual determination to perform the change which is motivated by the perceived benefits and compatibility of BIM innovation.

Table 8.27 Summary of the most important feedback loops influencing the three Stages of BIM Adoption Process (The UK Government Construction/BIM Strategy time horizon)

loops	Loop name	Interdependent factors	Indication
R1	Benefits of BIM innovation	Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶Relative advantage of BIM (F6)	The perceived benefits obtained from adopting BIM result in improving the organisation perception of BIM compatibility with experiences and current needs.
R2	Reinforcing visibility of BIM benefits	Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Observability of BIM (F3)	The visible and tangible benefits from successful BIM adoption motivate grater communication behaviours.
R3	Visibility of BIM benefits	Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6) ⟶ Observability of BIM (F3)	The visible and tangible benefits from successful BIM adoption lead to an increase in the perceived benefits obtained from adopting BIM.
R4	Organisational communication behaviour with BIM-centric social networks	Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2)	Greater communication behaviours lead to increase the visible and tangible benefits from successful BIM adoption.
R5	Organisational readiness to perform a change	Organisational readiness (F9) ⟶ Compatibility of BIM (F4) ⟶ Relative advantage of BIM (F6) ⟶ Observability of BIM benefits (F3) ⟶ Communication behaviour of an organisation (F2) ⟶ Organisational readiness (F9)	Organisation's members' mutual determination to implement a change leads to expanding the organisation's involvement with social networks interested in adopting BIM.
R6	Reinforcing organisational readiness to perform a change	Organisational readiness (F9) ⟶ Relative advantage of BIM (F6) ⟶ Organisational readiness (F9)	Promote the organisational readiness leads to an increase in the perceived benefits obtained from adopting BIM

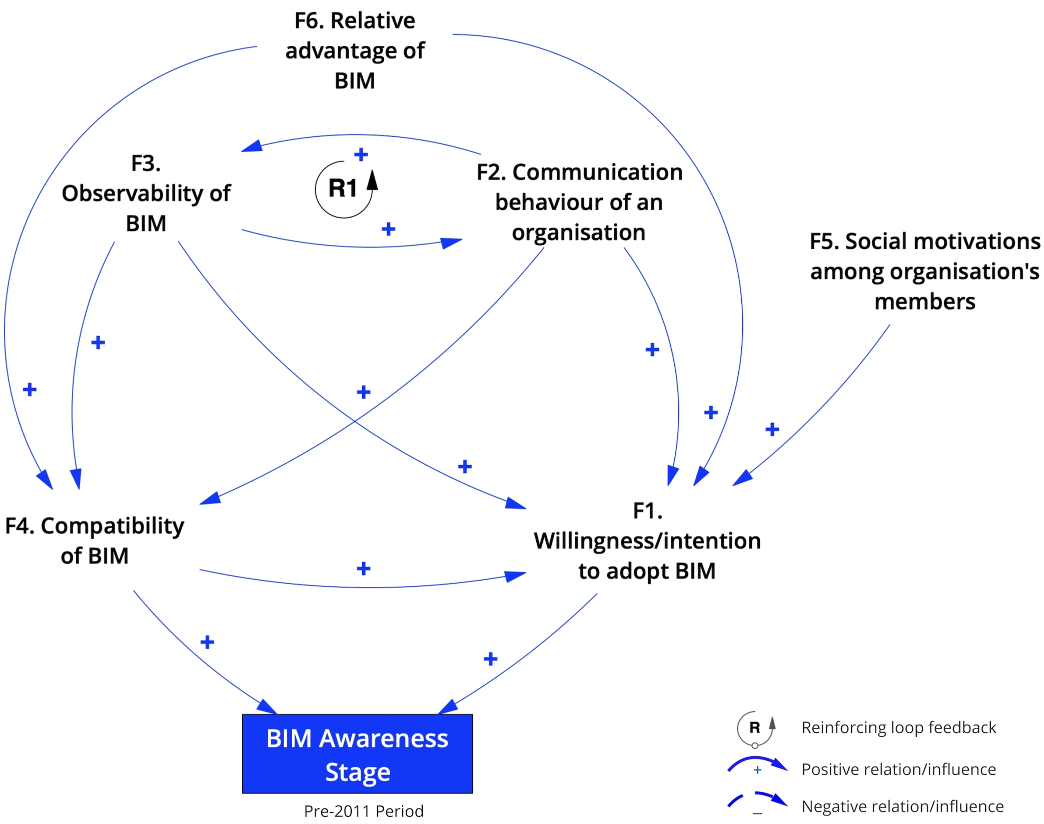


Figure 8.25 The Causal-Loop Diagram of the Systems Thinking Model of the Awareness Stage for the Pre-2011 Period

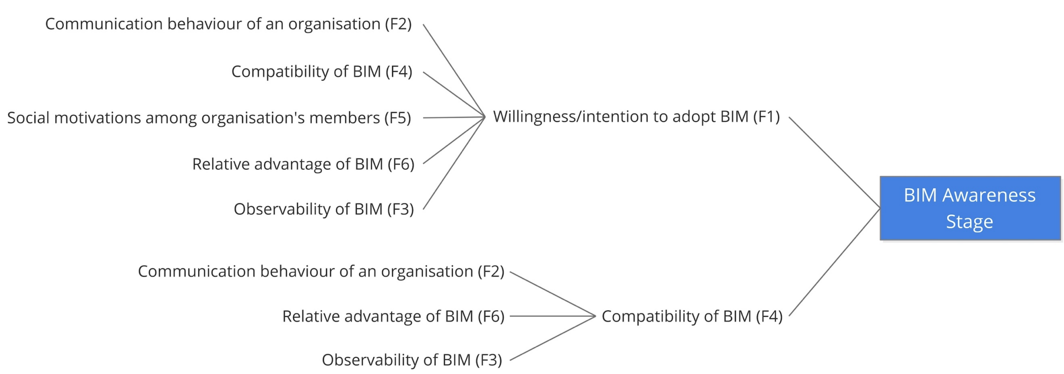


Figure 8.26 The causal relationships tree influencing the BIM Awareness Stage for the Pre-2011 Period

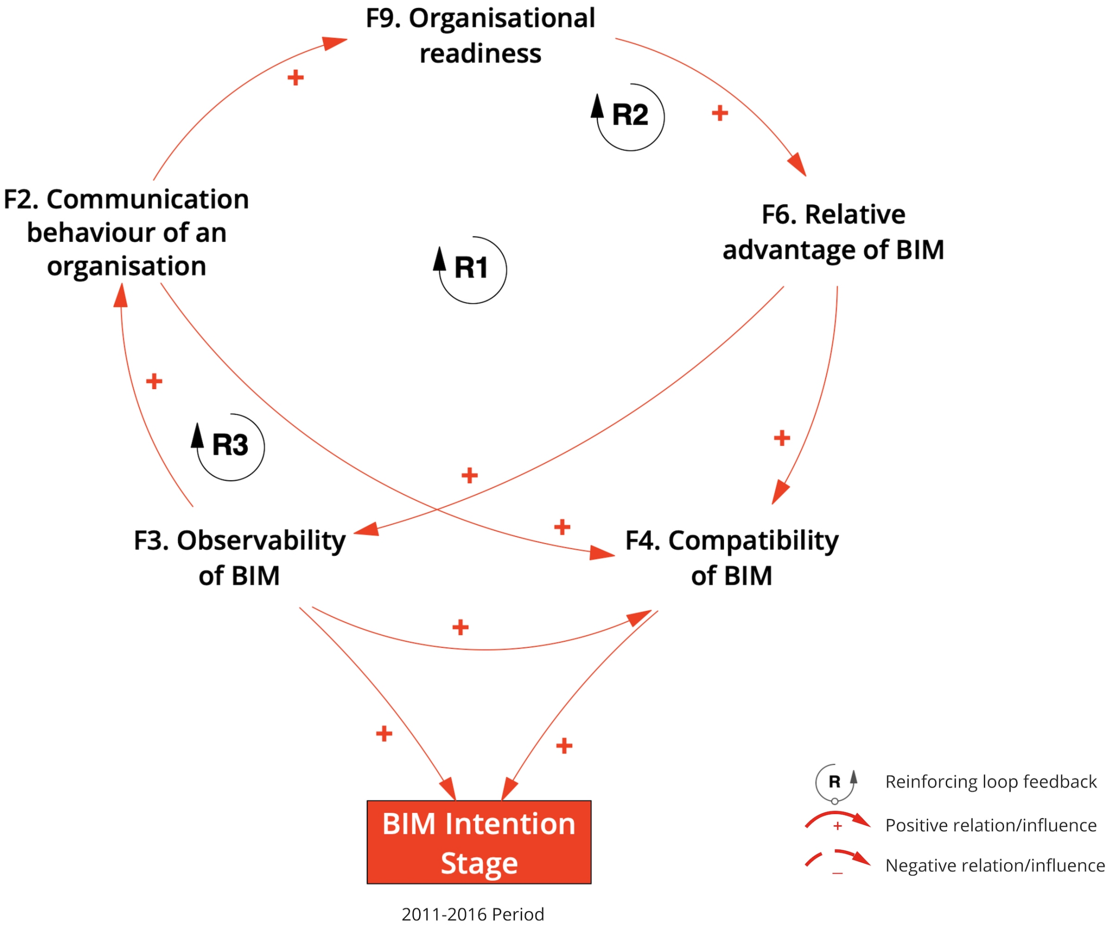


Figure 8.27 The Causal-Loop Diagram of the Systems Thinking Model of the BIM Intention Stage for the 2011-2016 Period

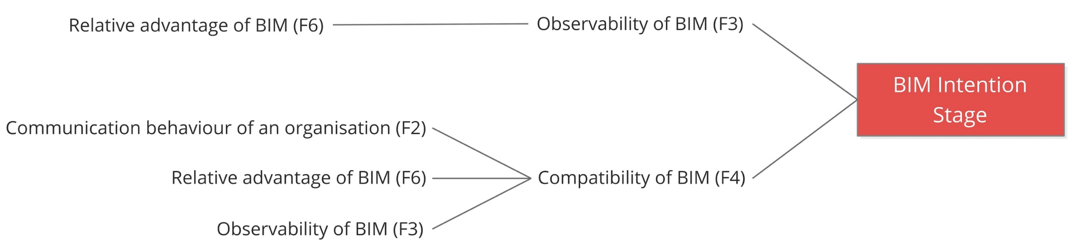


Figure 8.28 The causal relationships tree influencing the BIM Intention Stage for the 2011-2016 Period

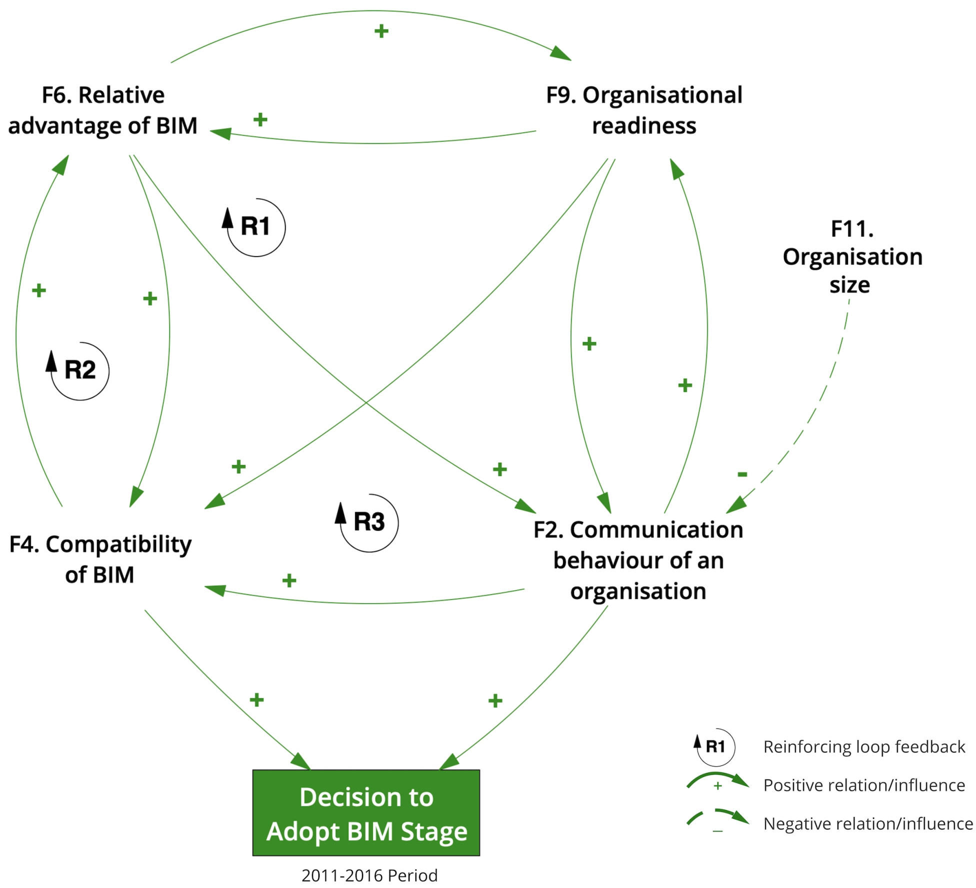


Figure 8.29 The Causal-Loop Diagram of the Systems Thinking Model of the Decision Stage for the 2011-2016 Period

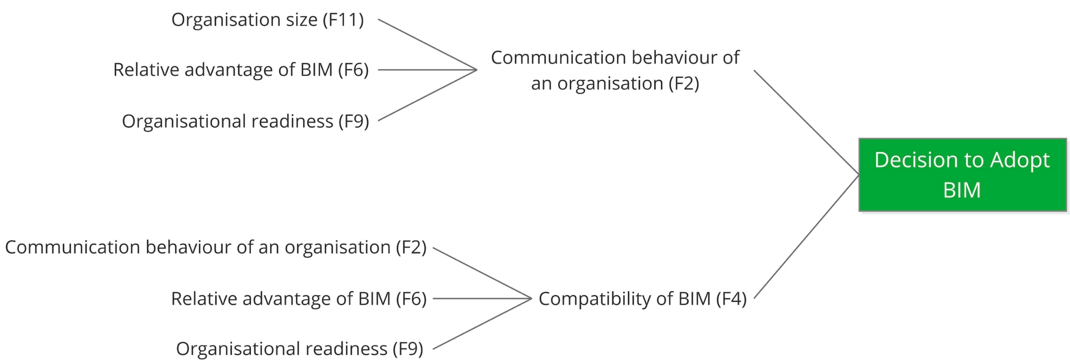


Figure 8.30 The causal relationships tree influencing the BIM Decision Stage for the 2011-2016 Period

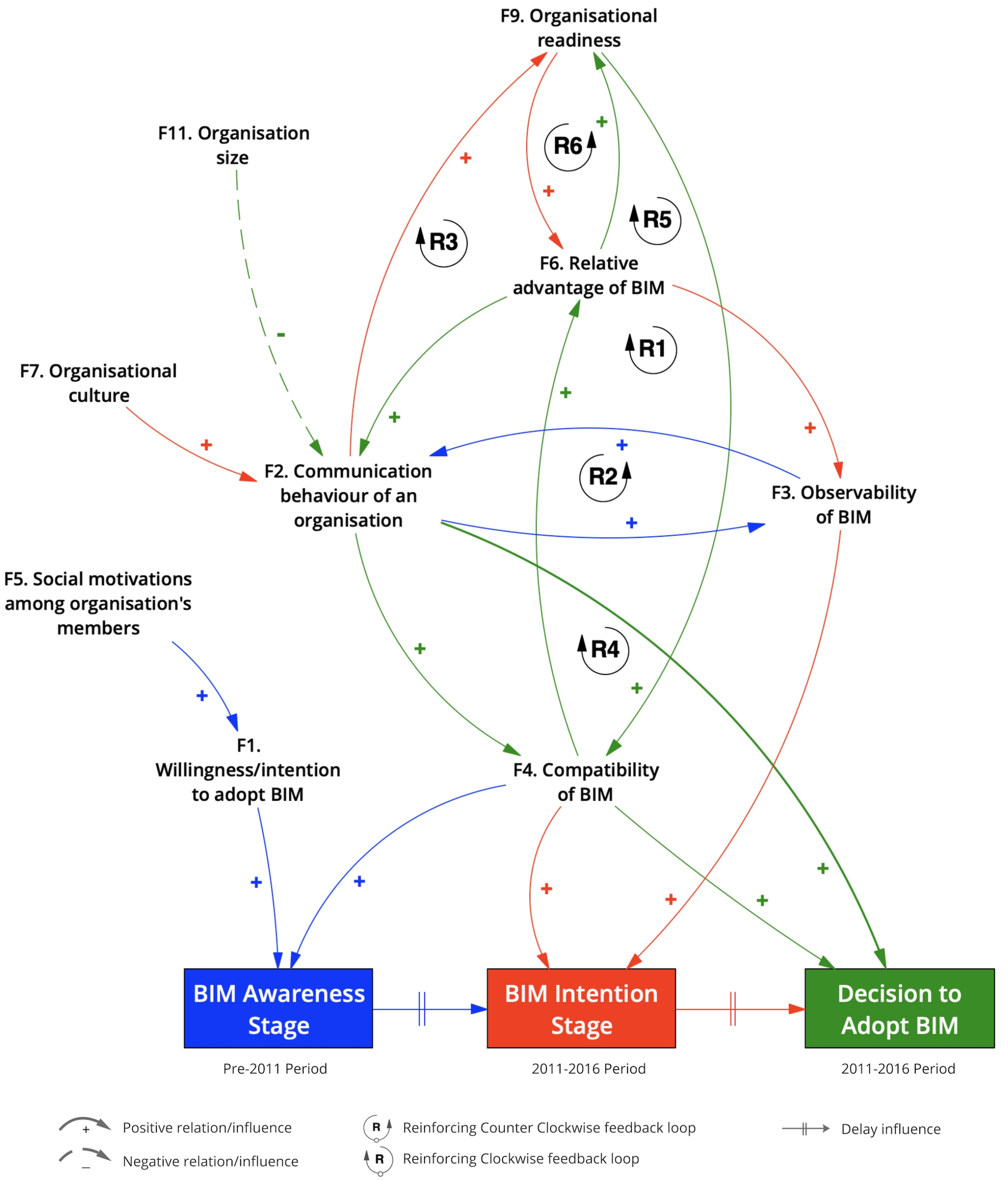


Figure 8.31 The Causal-Loop Diagram of the Systems Thinking Model of the three Stages of BIM Adoption Process (The UK Government Construction/BIM Strategy time horizon)

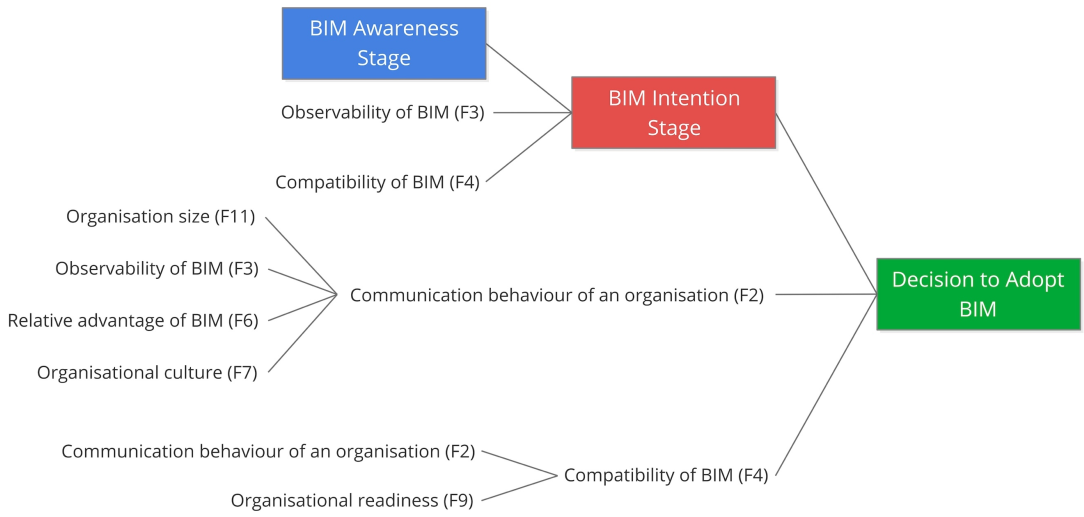


Figure 8.32 The causal relationships tree influencing the three Stages of BIM Adoption Process (The UK Government Construction/BIM Strategy time horizon)

8.4.3 Summary findings of the CLDs of Systems Thinking Models

As shown in Figure 8.23, the CLD model of the whole BIM Adoption Process (time-independent) provides six feedback loops that form a set of patterns. These patterns can help in analysing, understanding, and informing tailored policies, and action plans for micro BIM adoption within the architectural sector as shown with the subsequent examples. As a result, this model contributes to promote BIM adoption by clarifying the dynamics and patterns underpinning the BIM adoption process while focussing on the top drivers for adoption: the benefits of BIM innovation (Loop R1), visibility of BIM benefits (Loop R2), organisational readiness to perform a change (Loop R3), aligning BIM with experiences and needs (Loop R4), shared norms and beliefs among an organisation' members (Loop R5), and Organisational communication behaviour with BIM-centric social networks (Loop R6) (Table 8.23).

The CLD model of the individual BIM Adoption stages (time-dependent) decomposes the BIM adoption process into three consecutive stages (i.e., Awareness, Intention, and Decision) over three time periods – exemplifying key time intervals in the implementation of the UK national BIM initiative. It comprises seven feedback loops divided into the three stages of the common scenario of the UK example (No. 4).

This model can be utilised to inform the BIM adoption strategies at each stage. For example, it clarifies that the *Awareness Stage for the Pre-2011 Period* (Figure 8.25) the focus of an implementation plan should be on promoting the visibility of BIM benefits (Loop R1). At the *Intention Stage for the 2011-2016 Period* (Figure 8.27) a BIM implementation plan should be extended from focussing on the benefits of BIM innovation (Loop R1) to include organisational communication behaviour (Loop R2) and organisational readiness to perform a change (Loop R3). Finally, at the *Decision Stage of the 2011-2016 Period* (Figure 8.29) – similarly to the Intention stage – the emphasis should continue to be upon the benefits of BIM innovation (Loop R1), and organisational readiness to perform a change (Loop R2), and organisational communication behaviour (Loop R3). Hence, it can be seen that both the 'Intention' and 'Decision' stages share the same aspects but follow different paths (Table 8.24), (Table 8.25) and (Table 8.26).

Furthermore, it can be noticed from CLD, which combines the above-mentioned stages (Figure 8.31), that there is an emphasis on reinforcing the visibility of BIM benefits (at the Awareness and Decision stages) and organisational readiness to perform a change (at the Intention and Decision stages) (Table 8.27).

8.4.4 Systems Thinking Models: Discussion and implications

The systems thinking model – through its causal loop diagrams – provides a holistic view of the interacting variables/factors of the system (i.e., BIM adoption process). This section will show (1) how these results can provide researchers, decision-makers, and policy-makers with improved understanding of the adoption problem; and (2) how the results can be used to assist in identifying specific implementation measures that can promote BIM adoption according to the identified patterns.

The results showed that Relative advantage of BIM (F6) predominantly is the most important and influencing factor among all others across the stages of BIM adoption process. This factor represented the causal trigger whenever is involved in a direct influence or in an indirect feedback loop. Hence, Relative advantage of BIM (F6) is the key factor driving most adopters to make the decision to adopt BIM by architectural organisations.

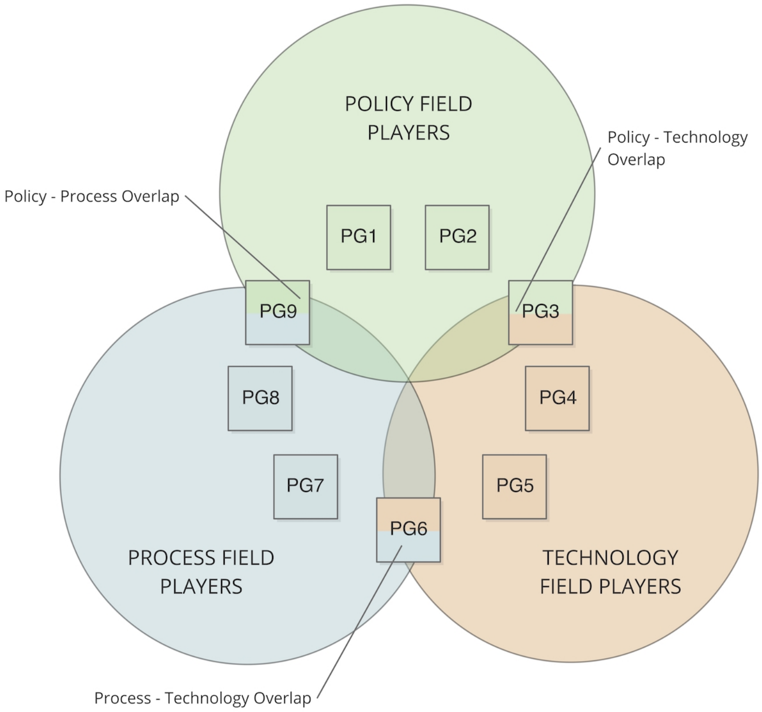
A few other factors [i.e., Communication behaviour of an organisation (F2), and Observability of BIM benefits (F3)] played a role as 'transitional' factors between every two consecutive stages. Factor (F3) has acted as a cause at the Awareness Stage while as an effect at the Intention Stage. Similarly, (F2) has acted as a cause at the Intention Stage while as an effect at the Decision Stage.

The interdependencies (i.e., direct and indirect influences, and reinforcing feedback loops) among the influencing factors, illustrated in the CLDs, provided several patterns that represent alternative dynamics involved in the BIM adoption process. The identification of such dynamics coupled with the conceptual organisation of such factors – involved in the systems thinking model – into the distinct constructs (i.e. BIM characteristics, Internal Environment Characteristics, and External Environment Characteristics) of the taxonomy can be exploited to inform BIM adoption policies and actions plans. For example, if these factors are linked to the industry player group(s) who can or should exert an influence upon them, the patterns identified in the systems thinking model(s) could be used to develop tailored BIM actions plans that support BIM adoption policies. An example of such use of the results is presented in this Section.

The 11 factors involved in the BIM Adoption process will be linked to industry Player Groups (PG), belonging to three BIM fields (i.e., policy, technology, and process) (Succar, 2009), based on the potential influence – exemplified through actions - that the industry PG) can/should exert to influence a given adoption driver. According to Succar and Kassem (2015), there are nine distinct groups of BIM players across three BIM fields (Figure 8.33). These BIM players groups are: Educational institutions (PG1), Policy-makers (PG2), Technology advocates (PG3), Technology service providers (PG4), Technology developers (PG5), Communities of practice (PG6), Individual practitioners (PG7), Construction organisations (PG8), and Industry associations (PG9). Mapping the factors of the developed systems thinking models (i.e. BIM adoption process) against these nine BIM players groups is based on the actions available to each player group and the effects of such actions on adoption factors. Adopting this rationale in conjunction with the findings about (1) the direct influences, indirect influences, and the reinforcing feedback loops among the factors within Systems Thinking models; and (2) the causality effect between factors from F-DEMATEL results, is used to show how the results can be used to inform BIM strategies / actions plans where industry player groups play a mutual and complement role to promote BIM adoption:

For example, to unlock BIM adoption according to loop **R1** (i.e., Benefits of BIM innovation in Table 8.23), industry players group can apply specific actions that are relevant to each driver. Such actions will have a primary effect on certain factors and secondary effect on others. In this instance, Policy-makers (PG2) supported by Industry associations (PG9), Educational institutions (PG1), and Technology advocates (PG3) can mutually exert a direct influence on Willingness to adopt BIM (F1); and an indirect influence on Relative advantage of BIM (F6), Observability of BIM benefits (F3), and Coercive pressures (Governmental mandate, informal mandate) (F10). This can be achieved by establishing and funding a dedicated BIM working group for the country (e.g., the BIM Task Group in the UK and its pertinent regional networks and hubs). Also, Policy-makers (PG2), Construction organisations (PG8), and Technology advocates (PG3), supported by Communities of practice (PG6) Industry associations (PG9), Individual practitioners (PG7), and Technology developers (PG5) can mutually have a direct influence on the Willingness to adopt BIM (F1), and Top management support (F8); and an indirect influence on Relative advantage of BIM (F6), Compatibility of BIM (F4), Observability of BIM benefits (F3), and Coercive pressures (Governmental mandate, informal mandate) (F10). This effect can be manifested through running pilot case studies and national surveys and publishing industry reports (best practice). In addition, Industry associations (PG9) supported by Technology service providers (PG4), Construction organisations (PG8), and Individual practitioners (PG7) can mutually exert a direct influence on Willingness to adopt BIM (F1), and Top management support (F8); and an indirect influence on Relative advantage of BIM (F6), and Compatibility of BIM (F4). This effect can be achieved through promoting the applicability of BIM technologies and providing professional and BIM technical staff training to the architectural organisations to align BIM technologies with existing processes without radical change (e.g., BIM Overlay to the RIBA Outline Plan of Work). The direct and indirect influence for all factors of this loop was determined based on the results from the F-DEMATEL and the CLDs of the whole BIM adoption process (time-independent) where Willingness to adopt BIM (F1), Social motivations among organisation's members (F5), Communication behaviour of an organisation (F2), and Top management support (F8) have all direct influence on the Decision to adopt BIM (As shown in Figure 8.4, Figure 8.23, and Figure 8.24). The suggested actions and initiatives of these player groups – for Loop **R1** – influencing relevant factors are listed in Table 8.28.

The illustrated example represents one of the scenarios in which the research findings can be exploited to show how a tailored action plan for encouraging BIM adoption can be developed and how the different industry player groups can play a mutual and complementary effort, each dedicated to unlocking one or more of the adoption factors. Several other scenarios could be developed for the different patterns and loop identified (e.g. for individual BIM adoption stages across the different stages of the time horizon underpinning a national BIM initiative). As a result, these findings and suggestions provide researchers, decision-makers, and policy-makers with an improved understanding of the investigated system and equip them with an analytically-driven approach to developing tailored appropriate approaches for BIM adoption and diffusion.



PG1 Educational institutions

Universities and other learning institutions which develop and/or deliver educational programs and learning material

PG2 Policy-makers

Authorities involved in mandating, regulating or facilitating the adoption of innovative systems/processes across an industry or a whole market (e.g. the BIM Task Group in the UK or BCA in Singapore)

PG3 Technology advocates

A formal grouping of individuals and organizations focused on the development/promotion of technology-centric standards and policies (e.g. buildingSMART or ACS)

PG4 Technology service providers

Commercial companies bridging the sales/services' gap between technology providers and end-users

PG5 Technology developers

Software, hardware and network solution providers with offerings targeted at whole industries or specific sectors, disciplines and specialties

PG6 Communities of practice

An informal groupings of individual practitioners with a common interest in a specific software, hardware or network solution (e.g. an ArchiCAD user group or SmartGeometry)

PG7 Individual practitioners

Practitioners (including students/ trainees) involved in learning or applying innovative systems/processes

PG8 Construction organisations

Large corporates and SMEs involved in deploying innovative systems/processes for commercial advantage (e.g. Multiplex or a local tiling company)

PG9 Industry associations

Associations representing the interests of their individual/ organizational members within a specific industry, sector, discipline or speciality (e.g. AIA, RIBA or APCC)

Figure 8.33 Macro Diffusion Responsibilities model and Players Groups Categories [Adapted from (Succar and Kassem, 2015)]

Table 8.28 A list of Actions by Primary and Supporting Player Groups influencing particular adoption factors (loop R1 Benefits of BIM innovation in Table 8.23)

Actions by Player Group(s)	Primary role	Supporting role	Adoption factors affected
Establish and fund a dedicated BIM working group for the country	Policy-makers (PG2)	Industry associations (PG9); Educational institutions (PG1); and Technology advocates (PG3)	**Direct:** Willingness to adopt BIM (F1) **Indirect:** Relative advantage of BIM (F6); Observability of BIM benefits (F3); and Coercive pressures (Governmental mandate, informal mandate) (F10).
Develop guidance and standardised templates to assist with implementation's time and cost.	Policy-makers (PG2)	Industry associations (PG9); Educational institutions (PG1); Technology developers (PG5);	**Direct:** and Willingness to adopt BIM (F1) **Indirect:** Relative advantage of BIM (F6); and Compatibility of BIM (F4).
Make tax regime favourable for BIM adoption (incentives in terms of tax rebates and tax credits) and provide incentives and funds for BIM adoption.	Policy-makers (PG2)	Industry associations (PG9); Construction organisations (PG8)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8). **Indirect:** Relative advantage of BIM (F6)
Develop/adapt BIM-era contractual agreements and other regulatory requirements	Policy-makers (PG2)	Industry associations (PG9); Educational institutions (PG1); Construction organisations (PG8); and Technology advocates (PG3)	**Direct:** Willingness to adopt BIM (F1) **Indirect:** Relative advantage of BIM (F6); and Compatibility of BIM (F4).
Assist in clarifying the value proposition of BIM with examples of performance (time, cost, predictability, etc.) benefits.	Construction organisations (PG8); Policy-makers (PG2); and Technology developers (PG5);	Technology service providers (PG4); Industry associations (PG9); Communities of practice (PG6); and Individual practitioners (PG7)	**Direct:** Relative advantage of BIM (F6); Willingness to adopt BIM (F1); and Top management support (F8) **Indirect:** Compatibility of BIM (F4); and Observability of BIM benefits (F3).
Provide technical guidance and support for BIM implementation.	Technology developers (PG5)	Communities of practice (PG6); Technology service providers (PG4); Policy-makers (PG2); Industry associations (PG9); Individual practitioners (PG7)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8) **Indirect:** Relative advantage of BIM (F6); and Observability of BIM benefits (F3).
Establish a network of seminars, workshops, knowledge sharing to introduce the benefits and potentials of BIM.	Policy-makers (PG2); and Industry associations (PG9); and Communities of practice (PG6)	Educational institutions (PG1); Technology advocates (PG3); Construction organisations (PG8): Technology service providers (PG4); and Technology developers (PG5)	**Direct:** Willingness to adopt BIM (F1); Communication behaviour of an organisation (F2); and Top management support (F8); **Indirect:** Relative advantage of BIM (F6); Compatibility of BIM (F4); and Observability of BIM benefits (F3).

Run pilot case studies and national surveys and publish industry reports (best practice).	Policy-makers (PG2); Construction organisations (PG8); and Technology advocates (PG3)	Communities of practice (PG6); Industry associations (PG9); Individual practitioners (PG7); and Technology developers (PG5)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8); **Indirect:** Relative advantage of BIM (F6); Compatibility of BIM (F4); Observability of BIM benefits (F3); and Coercive pressures (Governmental mandate, informal mandate) (F10).
Host BIM technologies camps, run pilot case studies/competitions, and sponsor BIM technologies awards to enable adopters (individuals and organisations) to experience BIM benefits and capabilities.	Technology developers (PG5)	Technology service providers (PG4); Construction organisations (PG8); and Communities of practice (PG6)	**Direct:** Willingness to adopt BIM (F1); Communication behaviour of an organisation (F2); and Top management support (F8). **Indirect:** Observability of BIM benefits (F3); Relative advantage of BIM (F6); and Compatibility of BIM (F4)
Encourage partnership/coalition approach to the adoption of BIM within the supply chain.	Construction organisations (PG8)	Policy-makers (PG2); Technology advocates (PG3); Individual practitioners (PG7); and Industry associations (PG9); and Educational institutions (PG1).	**Direct:** Willingness to adopt BIM (F1); Top management support (F8); and Communication behaviour of an organisation (F2) **Indirect:** Relative advantage of BIM (F6); Compatibility of BIM (F4); Observability of BIM benefits (F3); and Coercive pressures (Governmental mandate, informal mandate) (F10).
Influence organisational culture, structure and processes by empowering BIM champions / change agents.	Individual practitioners (PG7); and Construction organisations (PG8):		**Direct:** Organisational culture (F7); Communication behaviour of an organisation (F2); and Social motivations among organisation's members (F5) **Indirect:** Organisational readiness (F9).
Motivate organisation members to get involved in informal activities (e.g. BIM social networking and knowledge sharing events).	Construction organisations (PG8); Communities of practice (PG6); Industry associations (PG9)	Technology advocates (PG3); Technology service providers (PG4); Technology developers (PG5); and Individual practitioners (PG7)	**Direct:** Social motivations among organisation's members (F5); and Communication behaviour of an organisation (F2)
Increase the affordability of BIM technologies to adopters.	Technology developers (PG5); Policy-makers (PG2); and Technology service providers (PG4)	Construction organisations (PG8)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8).
Deliver special training of BIM technologies to individuals and organisations.	Technology developers (PG5); Educational institutions (PG1); and Construction organisations (PG8)	Technology service providers (PG4); Industry associations (PG9); Communities of practice (PG6); and	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8); **Indirect:**

		Individual practitioners (PG7)	Compatibility of BIM (F4): Relative advantage of BIM (F6); and Organisational readiness (F9).
Show and disseminate best practice on BIM to motivate other architectural organisations (i.e., potential adopters) towards BIM adoption.	Construction organisations (PG8); and Communities of practice (PG6)	Technology advocates (PG3); Technology service providers (PG4); Technology developers (PG5); and Individual practitioners (PG7)	**Direct:** Willingness to adopt BIM (F1); Top management support (F8); and Communication behaviour of an organisation (F2) **Indirect:** Relative advantage of BIM (F6); Compatibility of BIM (F4); and Observability of BIM benefits (F3).
Create upskilling BIM courses and CPDs dedicated for architectural organisations and provide consultations of how to achieve change towards BIM adoption.	Educational institutions (PG1)	Technology advocates (PG3); Technology service providers (PG4); Technology developers (PG5); Industry associations (PG9); and Individual practitioners (PG7)	**Direct:** Willingness to adopt BIM (F1); Top management support (F8); and Communication behaviour of an organisation (F2) **Indirect:** Compatibility of BIM (F4); and Organisational readiness (F9).
Improve the compatibility of BIM software, hardware and network solutions.	Technology developers (PG5); Technology service providers (PG4); and Technology advocates (PG3).	Communities of practice (PG6)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8). **Indirect:** Relative advantage of BIM (F6); and Compatibility of BIM (F4)
Develop digital collaboration platforms (e.g., servers and extranet for supply chain collaboration).	Technology developers (PG5); and Technology service providers (PG4);	Policy-makers (PG2); Technology advocates (PG3); and Educational institutions (PG1)	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8). **Indirect:** Relative advantage of BIM (F6); and Compatibility of BIM (F4)
Develop a BIM curricula for relevant architecture, built environment and engineering disciplines and participate in vocational training.	Educational institutions (PG1); Industry associations (PG9)	Technology developers (PG5); and Individual practitioners (PG7);	**Direct:** Willingness to adopt BIM (F1); and Top management support (F8); **Indirect:** Relative advantage of BIM (F6); and Organisational readiness (F9).

8.5 Summary and Conclusion

In this chapter, Systems Thinking Models of BIM Adoption Process were developed to further increase the understanding of the BIM adoption process by considering it as a complex system, and to explore the usefulness of the research findings in providing analytical insights to adopters and industry player groups that promote BIM adoption.

First, the employed fuzzy DEMATEL approach was demonstrated. Second, nine sets of the evaluation criteria of significance were analysed and discussed based on developing nine F-DEMATEL Models. The F-DEMATEL identified the impact of causal relationships amongst interacting criteria of factors that mutually influence the BIM adoption process. Third, a summary of the findings of the F-DEMATEL Models, including a discussion of the commonalities and differences and the identification of all possible adoption scenarios including the most representative scenario of the BIM adoption in the UK architectural sector, was presented (Hence, Objective 5 of this study is achieved). Fourth, the causal relationships of the F-DEMATEL together with the correlation analysis outcomes were incorporated to identify the causal feedback loops required to develop the Systems Thinking Models. Two main models were developed: The Systems Thinking Model of the whole system of BIM Adoption Process (time-independent) and the Systems Thinking Model of the individual BIM Adoption stages (time-dependent).

The result of this analysis showed that the CLD for the BIM adoption process as a single system (time-independent) provided six feedback loops that form a set of patterns. For example, this model contributes to promoting overall BIM adoption by identifying the key drivers that should be targeted by the adoption effort: the benefits of BIM innovation, visibility of BIM benefits, organisational readiness to perform a change, aligning BIM with experiences and needs, shared norms and beliefs among an organisation' members, and organisational communication behaviour with BIM-centric social networks.

Furthermore, The CLDs for the individual BIM Adoption stages (time-dependent) showed seven feedback loops divided into the three stages (Three sets of patterns). This model can be utilised to inform the BIM adoption strategies at each stage. For example, the Awareness Stage for the Pre-2011 Period focuses on promoting the visibility of BIM benefits. Both the Intention Stage and Decision Stage for the 2011-2016 Period concerns the benefits of BIM innovation, organisational communication behaviour with BIM-centric social networks, and organisational readiness to perform a change (i.e., sharing the same aspects but following different patterns).

Having demonstrated and discussed the patterns of the interdependencies and interrelationships for the Systems Thinking Models (based on the influences of the involved nine industry players groups), suggestions and implications of how these patterns may contribute to facilitating the BIM adoption process were discussed. These patterns resulted in a set of actions by Primary/leading and Supporting Player Groups influencing adoption factors (Thus, Objective 6 of this study is achieved). In conclusion, the chapter has enabled an improved understanding of the BIM adoption process and presented a novel and analytically driven approach to inform BIM adoption policies and actions plan.

Chapter 9 | Conclusion

9.1 Introduction

This ultimate chapter of the study, it demonstrates how all chapters of the thesis are linked and situated together, how the aim and objectives were addressed, and how the research questions were answered. Also, it shows how the thesis has contributed to the body of knowledge as well as the limitations and the recommendations for future research.

9.2 Research Summary

The investigation of the process of BIM adoption and diffusion has attracted considerable attention from industry and academia in recent years. Although the drivers and factors influencing BIM adoption were examined at different levels – ranging from individual and group through organisations and supply chains to whole market level –there is still a dearth of studies that extensively integrate drivers and factors affecting the decision to adopt BIM by organisations. Some of the key shortcomings include:

- Existing studies consider a partial array of adoption drivers limiting the opportunity of analysing complex interplays among the many factors affecting the BIM adoption process;
- Existing studies generally adopts specific theoretical lenses (e.g., Technology Acceptance Model) that also restrict the consideration of an extensive set of drivers;
- Research design is much of the existing studies does not enable the linking of the investigative effort (i.e. innovation adoption results) to policy maker's topics (i.e. market-wide BIM implementation strategies and role of industry player groups).
- Existing studies often seek to develop approaches for forecasting BIM

diffusion, and are generally focused on the diffusion phase, after BIM has been adopted;

- In many of the existing studies key terms and concepts (e.g., implementation, readiness, adoption, diffusion) are used interchangeably;
- Much of the existing studies are not explicit about the position of investigations in relation to the innovation adoption stages (i.e. Awareness stage, Intention stage, and Decision stage);
- There are limited investigations of interplays between adoption factors and specific instances of some factors such as organisation size (i.e., micro, small, medium, and large) and external isomorphic factors (e.g., market-wide BIM mandate by a government or a public agency) and how such interplays vary over time; and
- There is a dearth of investigative effort covering a whole sector (e.g., Architecture sector) within a defined market (e.g., the United Kingdom).

These shortcomings motivated the overall aim of this study set out in **Chapter 1**. Hence, the study aimed – as stated in the introduction of the thesis – at improving the understanding of the BIM adoption process within organisations and across markets by developing the necessary conceptual constructs and providing the supporting empirical evidence.

In **Chapter 2**, the necessary evidence proving the disruptive and multifaceted nature of BIM and justify the need for a new BIM innovation adoption research was provided. First, the most prominent BIM definitions were demonstrated. Then the existing literature was reviewed to provide evidence about the disruptive and multifaceted nature of BIM beyond the usual definitions. The UK construction industry was considered as an example of evidencing BIM as process, policy, and technology. Finally, the BIM adoption industry reports and the available BIM adoption academic research were demonstrated and discussed including the key areas, shortcomings, and possible opportunity to improve existing literature by addressing the dispersion of BIM adoption drivers and factors and develop an appropriate theoretical construct that synthesises this important knowledge area. This step was the point of departure to embark the next chapter (SLR).

Chapter 3 performed a Systematic Literature Review (SLR) to identify an extensive set of drivers (i.e., three driver clusters) and factors (i.e., 19 factors clustered under the three drivers) that influence the decision to adopt BIM by organisations, and the pertinent theoretical fundamentals and lenses (i.e., Innovation Diffusion Theory and Institutional Theory) (Objective 1). Having achieved this objective, this chapter informed *Objective 2* (i.e., in Chapter 5) by provided the theoretical prerequisites to develop a Unified BIM Adoption Taxonomy and a conceptual model to empirically examine the process of BIM adoption within architectural organisations.

Chapter 4 provided an explanation of the methodological and philosophical choices that underpinned this research and designed a three-phase research approach to carry out. ***Phase 1*** involved delivering background information about BIM and justifying the need for a new BIM innovation, and conducting a Systematic literature review (SLR) to identify the required drivers and factors and the pertinent theoretical fundamentals and lenses. Then, a Unified BIM Adoption Taxonomy (UBAT) was developed. ***Phase 2*** included the development and administration of a cross-sectional survey (i.e., 1st questionnaire) to collect primary data. The Confirmatory Factor Analysis (CFA) was used to validate the taxonomy. Next, 51 hypotheses were formulated, and Ordinal Logistic Regression analysis was used to test these hypotheses, and thus, the 11 most influencing factors were identified. Correlation Analysis was used to investigate the potential interplays among the 11 factors. The final step at this phase involved utilising knowledge synthesis approach to develop the Two-dimensional Characterisation Model of BIM adoption process. Finally, ***Phase 3*** comprised developing another questionnaire (2nd questionnaire) that informed the application of the F-DEMATEL. Systems Thinking Models were developed to map causal relationships and develop causal loop diagrams (CLDs). Then, the industry player group(s) were linked to the corresponding adoption factor to demonstrate how the results from the developed causal loop diagrams can inform the development and implementation of BIM adoption strategies. This Chapter also demonstrated the general survey results (i.e., demographic information) including organisation size, number of BIM projects, and certain dates/time horizons regarding BIM adoption decision.

In **Chapter 5**, a Unified BIM Adoption Taxonomy and a conceptual model for investigating BIM adoption decision by organisations was developed (Objective 2). The most widely used key terms and concepts explaining the diffusion of innovation processes were demonstrated. The BIM Adoption Taxonomy was proposed in the form of three hierarchical taxonomy levels (i.e., clusters) covering drivers, factors and determinants of BIM adoption (*BIM innovation characteristics*; the *external environment characteristics*, and the *internal environment characteristics*). The 17 constructs/factors of the proposed taxonomy were further examined considering the prior literature. Confirmatory Factor Analysis was used to empirically evaluate and validate the measurement models that represent the taxonomy's constructs which are developed in the form of Structural Equation Modelling (SEM). The validation of the proposed BIM adoption taxonomy was achieved by evaluating the validity and reliability of proposed CFA measurement models. Finally, the Systematic Literature Review findings and the developed taxonomy were used to develop a conceptual model for the empirical investigation of the BIM adoption process within organisations. The findings of this chapter were used to inform Objective 3 (in Chapter 6) and *Objective 4* (in Chapter 7).

In **Chapter 6**, a set of the most influential factors affecting the decision to adopt BIM by the architectural organisations within the UK's market was identified and ranked based on their power of influence at each stage of the BIM adoption process. First, 51 hypotheses were formulated and grouped into three main clusters based on the three characteristics drivers (i.e., external environment characteristics, innovation characteristics, and internal environment characteristics). These hypotheses were derived from the SLR findings and the taxonomy's constructs and their pertinent literature. Ordinal Logistic Regression analysis was employed to test the study hypotheses postulating relationship effects between each of 17 factors of the driver clusters (i.e., of the Unified BIM Adoption Taxonomy) and the three adoption stages (i.e., awareness, intention, and decision) based on BIM adoption process conceptual model that was developed in *Chapter 5*. Out of the 51, 22 hypotheses were approved and resulted in 11 factors with a positive and significant influence on the adoption stages. These factors were further ranked based on their power of influence. Finally, the findings of the Ordinal Logistic Regression analysis (i.e., the findings of each of the identified factors) were demonstrated and discussed with reference to the prior literature. This chapter informed *Objective* 4 in *Chapter 7*.

In **Chapter 7**, a Two-dimensional Characterisation Model for the BIM adoption process was developed using the knowledge synthesis approach (Objective 4). First, the 11 most influencing factors (i.e., resulted from achieving Objective 3) were tested using Correlation Analysis. The first cycle of the analysis resulted in a set of 39 pairs of strong positive relationships were identified as statistically significant. The second cycle of correlations analysis among the same 11 factors (i.e., while considering the three stages of BIM adoption process, and the time horizon of the UK Government Construction/BIM Strategy) resulted in a set of 31 pairs of strong relationships (28 strong positive relationships and 3 negative ones) that were statistically significant. The findings of the correlation analysis were further demonstrated and discussed. Some of the findings showed consistency with previous studies, while other findings indicated the possibility of the influence of certain factors/constructs to have an influence on other stages of BIM adoption process beyond what has been reported in previous literature. The Two-dimensional Characterisation Model for the BIM adoption process was developed using the knowledge synthesis approach. This model can help to better understand how pairs of factors can have different effects on various stages across different time horizons. Thus, the two-dimensional model helps in profiling the potential variations in the effect of adoption drivers on the different stages of BIM adoption. The findings of this chapter informed *Objective 5* and *6* in *Chapter 8*.

The completion of this thesis was undertaken in **Chapter 8**. In this chapter, Systems Thinking Models were used to explore of the BIM adoption process as a complex with the aim of improving our understanding of the adoption process and exploit the finding for the practical purpose of informing BIM adoption policies and action plans. First, fuzzy DEMATEL was employed to identifying the impact of causal relationships amongst complicated criteria of factors influencing BIM adoption process based on developing nine F-DEMATEL Models (Objective 5). An exhaustive list of the possible ten scenarios – including the representative scenario of the BIM adoption in the UK architectural sector – of BIM adoption process was identified.

The causal relationships of the F-DEMATEL together with the correlation analysis outcomes were incorporated to identify the causal feedback loops required to develop the Systems Thinking Models. Two main models were developed: The Systems Thinking Model of the whole system of BIM Adoption Process (time-independent) and the Systems Thinking Model of the individual BIM Adoption stages (time-dependent). This model can be utilised to inform the BIM adoption strategies at each stage. The patterns of the interdependencies and interrelationships for the Systems Thinking Models were demonstrated and discussed based on the influences of the involved stakeholders (i.e., the nine identified BIM players groups) (Objective 6). Finally, suggestions and implications of how these patterns may contribute to facilitating the BIM adoption process were discussed.

9.3 Reviewing the study objectives

In the following summary, an overview of how the overall aim of the study has been achieved through its six objectives is presented:

Objective 1: "*Identify an extensive set of drivers and factors that influence the decision to adopt BIM by organisations, and the pertinent theoretical fundamentals and lenses*"

This objective was addressed in *Chapter 3* by conducting a Systematic Literature Review. It provided the theoretical prerequisites to develop a Unified BIM Adoption Taxonomy and a conceptual model to empirically examine the process of BIM adoption within architectural organisations. The revealed findings were used to inform *Objective 2* in *Chapter 5*. A summary of the findings includes:

- A set of three *driver* clusters is identified including: BIM innovation characteristics (i.e., innovation perceived attributes); Internal environment characteristics (i.e., adopter or organisation readiness); and External environment characteristics (isomorphic pressures);

- 19 *factors* were identified under the three driver clusters. These key factors expanded into a list of exhaustive *determinants* which demonstrate the different manifestations of each driver (See Table 3.7, Table 3.8, and Table 3.9);
- Two pertinent theoretical fundamentals and lenses were identified including the Innovation Diffusion Theory (IDT) and Institutional Theory (INT); and
- 81% of the papers used quantitative statistical analysis and the survey-based questionnaire was used in 56% of the papers which makes it the most frequent data collection method used in the selected studies. Thus, this determined the selection of this study to adopt the quantitative approach for collecting and analysing the empirical data besides the quantifiable nature of the sought data.

Objective 2: "*Develop and validate a unified BIM adoption taxonomy of drivers and factors and a conceptual model to guide the empirical investigation of the BIM adoption process*"

This second objective was achieved in and related to *Chapter 5*. Part of this objective (i.e., the driver clusters and theoretical fundamentals) was informed by *Objective 1*. A summary of the findings of this objective includes:

- The most widely used key terms and concepts explaining the diffusion of innovation processes were demonstrated (e.g., implementation, readiness, adoption, diffusion). Hence, the key shortcoming of interchangeably using these terms – by the literature – is addressed;
- A Unified BIM Adoption Taxonomy (UBAT) – in the form of three hierarchical taxonomy levels (i.e., clusters) covering drivers, factors and determinants of BIM adoption – was developed and validated;
- A conceptual model for the empirical investigation of the BIM adoption process within organisations is developed; and
- Having achieved this objective, it enabled conducting a retrospective analysis of BIM adoption within a market (i.e., the United Kingdom) by considering a

sample of organisations that have already confirmed BIM.

Objective 3: "*Understand the effect of the taxonomy's drivers and factors on the BIM adoption by Architecture practices within the United Kingdom by identifying the most influencing drivers and factors on each of the three adoption stages (i.e., awareness, interest, and decision to adopt) and analysing their comparative influence*"

This objective was addressed in *Chapter 6*. An Ordinal Logistic Regression analysis was employed to test the study hypotheses postulating relationship effects between each of 17 factors of the driver clusters (i.e., of the Unified BIM Adoption Taxonomy) and the three adoption stages (i.e., awareness, intention, and decision) based on BIM adoption process conceptual model that was developed in *Chapter 5*. The findings of achieving this objective as follows:

- Out of the 17, 11 factors with positive and significant influence on the adoption stages were identified and ranked based on their power of influence (See Figure 6.2);
- Some particular factors – that belong to specific drivers – either they had an influence on other stages of BIM adoption process beyond what has been reported in previous literature, or had an influence only on stages instead of the expected ones (See Table 6.12); and
- Except for the influence of the Coercive pressures (i.e., formal and informal mandate) on the '*Intention*' and '*Decision*' Stages, there was no evidence that both the 'mimetic pressures' and 'normative pressures' affected the three stages.

Finally, *Objective 3* together with *Objective 2* informed achieving *Objective 4* in *Chapter 7*.

Objective 4: "*Develop a two-dimensional characterisation model of BIM adoption including interplays between correlated pairs of adoption factors, and time (i.e., three time periods including pre-mandate period, implementation/trial period, and post-mandate period)*"

This fourth objective was achieved in *Chapter 7*. The findings can be summarised as follows:

- 39 pairs of strong positive relationships were identified – from the first cycle of the correlation analysis – as statistically significant (See Table 7.2);
- A set of 31 pairs of strong relationships (28 strong positive relationships and 3 negative ones) that were statistically significant – from the second cycle of the correlation analysis considering the three stages of BIM adoption process, and the time horizon of the UK Government Construction/BIM Strategy (See Table 7.6);
- Some pairs of factors (e.g., Communication behaviour ⟺ Compatibility) have a continuous influence by transferring their effect (a) across three consecutive stages within two periodical time-horizon (i.e., from 'Awareness' to 'Intention' in Pre-2011, then from 'Intention' to 'Decision' in 2011-2016) and (b) across two consecutive periodical time-horizon of the same stage (i.e., from Pre-2011 to 2011-2016 at 'Intention') (Figure 7.5, Figure 7.7, and Figure 7.11). Thus, such correlations may (1) prompt the organisations' *awareness* to gain more knowledge about BIM; (2) formulate and develop a favourable attitude (i.e., Intention) of organisations towards BIM adoption; and then (3) enable the architectural organisation to make the decision to adopt BIM; and
- A Two-dimensional Characterisation Model for the BIM adoption process was developed using knowledge synthesis approach. This model can help to better understand how pairs of factors can have different effects in various stages across different time horizons (See Figure 7.12);

Finally, *Objective 4* informed achieving *Objective 6* in *Chapter 8*.

Objective 5: "*Explore the BIM adoption process as a complex system through the application of structural modelling (i.e. Decision-making trial and evaluation laboratory – DEMATEL) to cluster adoption factors into cause and effect groups, and systems thinking techniques to map causal relationships and develop causal loop diagrams*"; and

Objective 6: "*Demonstrate how the results from the developed causal loop diagrams can inform the development and implementation of BIM adoption strategies*"

Both objectives were addressed in *Chapter 8*. The findings of achieving these objectives as follows:

- Nine Fuzzy DEMATEL Models were developed based on identifying the impact of causal relationships amongst complicated criteria of factors influencing BIM adoption process (i.e., the first part of Objective 5);
- The commonalities and differences of the influence among the F-DEMATEL Models of the three stages over three-time horizons were identified (See Table 8.22);
- An exhaustive list of the possible ten scenarios – including the representative scenario of the BIM adoption in the UK architectural sector – of BIM adoption process was identified (See Figure 8.21);
- Systems Thinking Models to explore of the BIM adoption process as a complex were developed (i.e., the second part of Objective 5). These models include the CLD of the whole system of BIM adoption process (time-independent) and the CLD of the individual BIM adoption stages (time-dependent); and
- The patterns - resulted from the CLDs loops – of the interdependencies for the Systems Thinking Models were mapped against the involved stakeholders (i.e., the nine identified BIM players groups) (Objective 6). These patterns can be used in analysing, understanding, and informing desired policies, tailored action plans, and initiatives regarding micro BIM adoption within the architectural sector.

9.4 Key Findings of the Research

This study provided an in-depth analysis of the BIM adoption process within organisations. It developed a unified BIM adoption taxonomy that contains an extensive array of adoption factors. Following the validation of the taxonomy, its factors were used within a proposed conceptual model, which combined the Innovation Diffusion Theory with the Institutional Theory, to perform a multifaceted analysis of the BIM adoption process. A set of 11 most influencing factors on BIM adoption process was identified and included: *Willingness to adopt BIM*, *Communication behaviour of an organisation*, *Observability of BIM benefits*, *Compatibility of BIM*, *Social motivations among organisation's members*, *Relative advantage of BIM*, *Organisational culture*, *Top management support*, *Organisational readiness*, *Coercive pressures (Governmental mandate, informal mandate)*, and *Organisation size*. Focussing on these 11 most influencing factors, several analyses were performed to understand the interplays between these factors – while considering specific instances of certain factors (i.e., organisation size, and external isomorphic pressure) over time (i.e., Pre-2011, 2011-2016, and Post-2016 exemplifying three key time periods in the UK national BIM strategy).

The F-DEMATEL identified the impact of causal relationships amongst interacting criteria of factors that mutually influence the BIM adoption process. The classification of factors into cause and effect groups using the DEMATEL provided a new understanding of the independencies between factors which can be used to tailor and prioritise implementation actions and investments. An exhaustive list of the possible ten scenarios – including the representative scenario of the BIM adoption in the UK architectural sector – of BIM adoption process was identified based on the F-DEMATEL findings.

The results showed that the *relative advantage of BIM* is the most important and influencing *factor* across all the three stages of the adoption process (i.e., Awareness stage, Intention stage, and Decision stage) of the BIM adoption process. *Coercive pressures (e.g. Governmental mandate, informal mandate)* had a direct influence on both formulating the *intention* and the *decision* to adopt BIM across two periods of the three-time horizons (i.e., Pre-2011and Post-2016). For the Pre-2011 period, the coercive pressures were mostly informal mandate/pressures by the parent companies and partners, while during Post-2016 periods, it was predominantly the UK Government mandate which was announced in 2011 and entered into effect in 2016.

It is worth pointing out that 18% of the architectural organisations (i.e., the total collected sample of 177 organisations) made the decision to adopt BIM in the Pre-2011 period due to the informal pressures by the parent companies and partners. While in the 2011-2016 period, the percentage was 59% of those who made the decision without reporting any direct influence of the coercive pressures. Finally, in the Post-2016 period, the percentage was 23% due to due to the combined coercive pressures – a formal mandate by the government and informal pressures by the partners and parent companies.

Several Systems Thinking models were developed to show the interdependencies among the factors that affect the BIM adoption process at different time periods and stages of the BIM adoption process. Such models infer patterns of behaviour of BIM adoption as complex systems and can be used to guide the development and implementation of BIM strategies. The findings can be exploited to show how a tailored action plan for encouraging BIM adoption can be developed and how the different industry player groups can play a mutual and complementary effort, each dedicated to unlocking one or more of the adoption factors. Several other scenarios could be developed for the different patterns and loop identified (e.g. for individual BIM adoption stages across the different stages of the time horizon underpinning a national BIM initiative). As a result, these findings and suggestions provide researchers, decision-makers, and policy-makers with an improved understanding of the investigated system and equip them with an analytically-driven approach to developing tailored appropriate approaches for BIM adoption and diffusion.

9.5 Conclusions

9.5.1 Hypothesis and Research questions

The study investigation initially resulted from this hypothesis:

"*The decision to adopt BIM by architectural organisations – as a selected speciality cluster within the construction sector for this study – is a complex process entailing multiple stages that are mutually affected by several adoption drivers and factors. The understanding of this process can be achieved through the development and application of a conceptual model that allows the analysis of the effect by and interplays among an extensive array of adoption drivers.*"

Having achieved the objectives of this study, it becomes possible to address the above hypothesis and answer posed questions as follows:

(1) *How the development of a unified BIM adoption taxonomy can inform the analysis and understanding the BIM adoption process by architectural organisations?*

Answering this question is multifold: first, demonstrating the most widely used key terms and concepts explaining the diffusion of innovation processes (e.g., implementation, readiness, adoption, diffusion) has addressed the key shortcoming of interchangeably using these terms – by the literature; second, the unified BIM adoption taxonomy has provided three validated hierarchical taxonomy levels (i.e., clusters) covering drivers, factors and determinants of BIM adoption; third, the taxonomy and its pertinent constructs helped in developing a conceptual model for the empirical investigation of the BIM adoption process within organisations. Thus, all the latter stages of analysis were built upon the developed taxonomy that provided a granular level of explanation across this thesis.

(2) *What are the key drivers that affect BIM adoption within architectural organisations?*

Three key drivers – in the form of three hierarchical taxonomy levels (i.e., clusters) – have been identified. These are the BIM innovation characteristics, the external environment characteristics, and the internal environment characteristics. A set of 17 factors is identified, however, only 11 factors corresponding to the UK Architectural sector were identified and validated as the most influencing factors on the decision to adopt BIM. These factors are: *Willingness to adopt BIM*, *Communication behaviour of an organisation*, *Observability of BIM benefits*, *Compatibility of BIM*, *Social motivations among organisation's members*, *Relative advantage of BIM*, *Organisational culture*, *Top management support*, *Organisational readiness*, *Coercive pressures (Governmental mandate, informal mandate)*, and *Organisation size*. Each of the factors was manifested in various forms (i.e., a single factor, cause-effect pair of factors, and interrelated factors within a complex system) based on the power of influence at certain stages and time horizon of the BIM adoption stage. The influence of these drivers and their factors is a context-based corresponding to a certain market that varies according to the multi-stage nature of BIM adoption process and the time horizon.

(3) *How both the BIM adoption taxonomy and the existing studies related to innovation adoption can be used to develop a conceptual model to guide the investigation of the BIM adoption process in architectural organisations?*

The developed model merges together an adapted view of the innovation adoption process by Rogers (2003) and key conceptual constructs of the Innovation Diffusion Theory (IDT) and Institutional Theory (INT). The IDT provides the theoretical requisites for investigating the effect of both the BIM characteristics (i.e., innovation attributes) and the organisation's internal environment characteristics (i.e., adopter or organisation readiness) on the BIM adoption process. The INT will help to investigate effect of the external environment characteristics (i.e. institutional isomorphic pressures).

Finally, this study – across the thesis chapters and the pertinent objectives – has presented a roadmap to a better understanding of the BIM adoption process. It is commencing from identifying (a) extensive sets of drivers and factors (i.e., Systematic Literature Review in Chapter 3); then identifying (b) the 11 most influencing factors on BIM adoption process (i.e., Ordinal Logistic Regression in Chapter 6); moving to identifying (c) a set of pairs of correlated factors (i.e., correlation analysis in Chapter

7); reaching to (d) causal relationships interacting factors (i.e., F-DEMATEL) and (e) developing loops of interrelated factors within a single complex system (i.e., Systems Thinking Models/CLDs in Chapter 8).

9.5.2 Contribution to Knowledge

9.5.2.1 Empirical contribution

The key knowledgeable deliverables can be used to perform various analyses of the BIM adoption process, providing evidence and insights for decision-makers within organisations and across a whole market when formulating BIM adoption and diffusion strategies. In particular, they can assist researchers, decision-makers, and policy-makers with a better understanding of the BIM adoption process and can guide the development of BIM strategies and plan for BIM adoption and diffusion. Ultimately, they contribute to promote BIM adoption within the architectural sector through the suggested adoption patterns.

9.5.2.2 Theoretical contribution

At a global level (overall aim), this study provided an understanding of how intra-organisational BIM adoption and inter-organisational BIM diffusion occurs. At a local level (individual objectives), the key knowledge deliverables in this study (i.e., the taxonomy, a conceptual model for BIM adoption process, two-dimensional characterisation model of BIM adoption, and systems thinking models) and the empirical investigation represent a new contribution to knowledge with each contributing from a specific standpoint. These theoretical contributions are summarised including:

- The Unified BIM Adoption Taxonomy is the first – if not the sole – statistically validated BIM adoption taxonomy that includes an extensive array of adoption drivers and factors and combines constructs from both the Institutional and the Innovation Diffusion theories.
- The conceptual model for analysing BIM adoption and its use for the empirical

investigation of BIM adoption within the UK Architecture sector explored and identified relationships that were not known before (i.e., triggering the BIM Awareness and formulating an Intention about BIM adoption is not limited to Internal Environment Characteristics and the Innovation Characteristics respectively - as suggested by Rogers' theory, but occurs by a combination of both characteristics).

- The two-dimensional characterisation model of BIM adoption clarified new interplays between adoption factors, and time (i.e., pairs of positively and negatively correlated factors vary based on adoption stages and time horizon).
- The classification of factors into cause and effect groups using the DEMATEL provided a new understanding of the independencies between factors which can be used to tailor and prioritise BIM implementation actions and investments.
- The developed Systems Thinking Models enabled a detailed analysis of mutual interactions between adoption factors as part of causal relationship networks. The developed instances of such models for different temporal scenarios and stages of the BIM adoption stage can be exploited by the industry player groups (i.e., Policy-makers, decision-makers, change agents, etc.) to promote BIM adoption process within the organisations and BIM diffusion across a market.

9.5.3 Study limitations

- The development of the taxonomy was based on a systematic literature review process. Although it is an extensive, detailed and replicable method, the limitations associated with any systematic literature review such as the possibility that the review omits some relevant studies apply.
- At earlier stages, this study was set out to use mixed-methods (i.e., quantitative and qualitative approaches). However, the researcher has decided to adopt a mono-method (i.e., a quantitative strategy but including multi-techniques). This is due to (a) quantitative nature of the questions and required data (based on the aim of this study); (b) a limited availability and access to existing internal and external agents of change who are knowledgeable about the

occurrence of the BIM adoption process within architectural organisations; (c) architectural organisations are reluctant to reveal information regarding their 'know how' of practicing BIM; and (d) the constraints related to data confidentiality and Non-Disclosure Agreement (NDA) that makes the accessibility to case studies, and conducting a semi-structured interviews with those practitioners almost impractical.

- The positivist paradigm adopted in this study has some limitations that are reportedly mentioned in the literature. With a positivist paradigm, it is challenging to quantify a phenomenon associated with human's intention, beliefs, and attitudes since these perceptions may not clearly be measured or perceived based on sense experience or without proof. It is difficult to address abstract concepts which usually evolve around the human relationship (e.g., people's interpretation of their actions and others). Hence, with the positivist approach, there is a risk of neglecting individuals' interpretations and understanding regarding some occasions, issues, and phenomena that can uncover many facts about reality. However, this study does not require capturing human-social behaviour or interpretation of a social phenomenon; rather, it seeks explicit responses regarding the adoption of particular innovation (i.e., BIM) and the organisational actions and milestones of the adopters. Therefore, the mentioned limitations are unlikely to have a negative impact on the rigour of data collection and analysis performed in this study. This was also aided by the quantitative nature of the research questions and the required data to address this study's aim and objectives – that did not involve interpreting deeply human behaviours or social reality.

9.5.4 Recommendations and Future research

A set of recommendations for future research is derived from the development and the findings of this study including:

- This research has been carried out based on a representative sample of a specific country (i.e., the UK Architectural Sector as an example) although its underlying principles could be directly adapted and applied to other countries while considering their contextual and national accounts. For example, it could be applied to a country with/without market-wide pressures (e.g., BIM mandate) and markets affected by different isomorphic and institutional pressures.

- The 11 most influencing factors -identified in this study – could be used in studies aiming to forecast the BIM adoption and diffusion at the micro level.
- This study has investigated the influence of drivers and factors of the process of BIM adoption considering a single market (i.e., the UK). However, it is important to evaluate and compare how such drivers and factors may impact the BIM adoption process within multiple markets. This involves examining the role of and interrelationships between BIM adoption drivers/factors across markets recognised for their various diffusion dynamics (e.g., the top-down, the middle-out, and the bottom-up dynamics). The comparability of findings would provide further novel insights about the BIM adoption process at organisational levels and its interplays with market-wide characteristics.
- A future study adopting deploying qualitative approaches using the most influencing adoption factors to explore their effect on inter-organisational and intra-organisational process of BIM adoption would be interesting for a comparability purpose.
- The Causal Loop Diagrams developed as part of the systems thinking model, when coupled with the actions of the industry player groups and their respective effects, can be used to formulate systems dynamics to simulation BIM adoption under different BIM policies and scenarios.

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Appendices

Appendix A

Table A.1 An example of a data extraction card

Study number	S3
Name of the study	Understanding and facilitating BIM adoption in the AEC industry
Author(s)	(Gu and London, 2010)
Year	2010
Publisher (Journal/conference)	Journal: Automation in Construction
Country	Australia
Study methods considered for data collection	Focus group interviews
Study type of analysis	Qualitative Content analyses
Target level (Macro, Meso, Micro)	Project level adoption (Meso)
Name/Type of innovation	BIM adoption
Applied /adopted theories, frameworks, processes, and models attributed to BIM/innovation	Development of the Collaborative BIM Decision Framework to discuss and analyse the understanding and facilitating the readiness BIM adoption regarding (1) product, (2) processes and (3) people, to situate BIM adoption in terms of current position and anticipations across various disciplines. Hence, the proposed Collaborative BIM Decision Framework needs to be modified based on the individual organisations requirements or specific projects requirements.
Identified drivers and factors influencing BIM/innovation adoption (implementation and diffusion)	This research has identified two main categories that are influencing BIM adoption, which can be grouped into these areas: technical tool managing needs and requirements, and non-technical strategic matters. In addition, it could be argued that a wider BIM adoption is very promising with the sharper identification and steady proliferation of various business drivers regarding sustainable design and construction initiatives for changes owing to the necessities of sustainable design and construction, precise as-built data for facilities management, as well as the comprehensive multi-disciplinary collaboration. Further factors could also be: work practice, organisational structure, business interest, staff training.
Current researcher reflection/review/critique	This research has addressed the varying levels of BIM adoption within countries despite the relative clarity of the potential benefits of BIM. It has revealed that in many cases, even the market leaders, the early adopters, they have different levels of confidence and different understanding of future diffusion of BIM within the Australian industry since they have various degrees of experiential knowledge of BIM. Also, it has indicated that how the diffusion of innovative technologies is impacted by the valuable experiences of adopters and the ability to adapt these technologies to outfit the particular needs of individual organisations in terms of successfully sustain and/or improve the advantages of the competitive business. Hence, the proposed Collaborative BIM Decision Framework requires to be modified based on the individual organisations requirements or specific projects requirements. However, despite providing rigor evidence concerning the understanding of the readiness of BIM adoption, the findings of study might have been more convincing if the authors had adopted, to some extent, a diffusion model to discuss the study results rather than widely relying on their proposed BIM Decision Framework.

Appendix B First questionnaire (Main data collection tool)

BIM Adoption by Architectural Organisations

* Required

Invitation/Consent Form

I am a PhD researcher at the School of Architecture within the University of Sheffield (UK), under supervision of Dr John Kawalek, Dr Mohamad Kassem, and Dr Stephen Walker. My research aims to investigate the drivers and factors that influence the decisions of architectural organisations to adopt Building Information Modelling (BIM).

The research focuses on organisations that have already adopted BIM. The participants should be knowledgeable about the process that led their organisation to adopt BIM.

The research is conducted in accordance with the Sheffield University policy on data storage and it has been ethically approved by the School of Architecture.

It approximately takes less than 12 minutes to answer this questionnaire.

1- I confirm that I have read and understand the information/invitation that explains the above research project.

2- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.

3- I give permission for members of the research team to have access to my anonymised responses. I understand that my name and my organisation's affiliation will not be linked with the research materials, and will not be identified or identifiable in the report or reports that result from the research.

We greatly appreciate your support and we thank you for your contribution.
Ahmed L. Ahmed

Please choose only one: *

- I agree
- I disagree

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General Information

1- What is the size of your organisation (practice, company, firm, etc.)?

- ◯ Micro: less than 10 employees
- ◯ Small business: 10 - 49 employees
- ◯ Medium-sized business: 50 - 249 employees
- ◯ Large business: 250 employees or more

2- Approximately, when did your organisation first hear about BIM? [Year]

3- Approximately, when your organisation has had the intention (formulated a favourable attitude towards BIM) to adopt BIM? [Year]

4- Approximately, when did your organisation make the decision to adopt BIM? [Year]

5- How many BIM projects does your organisation participate in so far?

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External Environment Characteristics

To what extent do you agree or disagree with the following statement:

1- Our main clients believe that we should use BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

2- Our trading partners put pressure upon us to use BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

3- We may not retain our important clients without BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

4- We have adopted BIM to respond to the BIM level 2 mandate by the UK government.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

5- Non-adoption of BIM, may lead to contractual sanctions.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

6- Our main competitors have adopted BIM and benefited from it.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

7- Our main competitors who have adopted BIM are perceived favourably by clients.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

8- Our main competitors who have adopted BIM are more competitive.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

9- It is important to benchmark our BIM adoption against our main competitors.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

10- Potential BIM adopters may imitate their main competitors' implementations.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

11- Potential BIM adopters imitate the behaviour of other firms within their network.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

12- BIM has already been widely adopted by our clients.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

13- BIM has been widely adopted by the architectural, engineering, and construction industry (AEC).

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

14- The BIM norms, standards, and policies motivated and helped our organisation to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

15- BIM champions played a significant role in BIM diffusion.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

16- The BIM external consultants influenced and facilitated our decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

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BIM Perceived Attributes

To what extent do you agree or disagree with the following statement:

17- Adopting BIM is perceived to improve the productivity of our organisation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

18- Adopting BIM is perceived to reduce overall cost.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

19-Adopting BIM is perceived to shorten duration of a construction project.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

20- Adopting BIM can mitigate risk.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

21- Adopting BIM is perceived to improve task performance.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

22- Adopting BIM is perceived to be advantageous in our organisation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

23- Adopting BIM is perceived to be compatible with existing processes in our organisation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

24- Adopting BIM is perceived to be compatible with our organisation culture and values.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

25- Adopting BIM makes our work easier.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

26- We adopted BIM because it is easy to learn.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

27- Adopting BIM is perceived to improve collaboration in our organisation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

28- Adopting BIM is perceived to be too complex for business operations.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

29- Trying out BIM features before adoption in practice provides the possibility of risk reduction.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

30- We adopted BIM after a trial period.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

31- The positive results of adopting and implementing BIM support its diffusion.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

32- We adopted BIM as its positive effects were evident.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

33- Our organisation has the intention to recommend BIM to others.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

34- BIM interoperability across different platforms was key in the decision to adopt.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

35- Adopting BIM is perceived to improve the visualisation of design effects.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

36- The availability and affordability of BIM technology were key in the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

37- The investment cost of BIM technology (software, hardware, training) did not affect our decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

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Internal Environment Characteristics

To what extent do you agree or disagree with the following statements:

38- Our top management has the willingness to support change.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

39- The general attitude of our organisation towards innovation facilitates the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

40- The senior management of our organisation encouraged the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

41- Our organisation has effective communication channels and networking within the

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

architectural, engineering, and construction industry (AEC).

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

42- Our organisation initiated a network of connections to know more about BIM when we first time had heard about it.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

43- Our organisation has direct communication with the early adopters of BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

44- The internet/social media helped our organisation to understand more about BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

45- Interpersonal channels helped our organisation to understand more about BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

46- Our organisation has allocated a yearly budget for IT technologies that facilitated the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

47- The required cost to secure BIM was a key element in the decision to adopt.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

48- Our organisation perceived BIM as an affordable innovation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

49- Our organisation has adopted BIM as its implementation cost was affordable.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

50- Our organisation has provided sufficient training to our staff as a preparation for BIM adoption.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

51- Our ability to adapt the technologies enabled us to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

52- Our organisation has provided a professional BIM technology training.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

53- Technological capability of organisation is key to the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

54- Our organisation has employed experienced staff to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

55- Our organisation has the capability of training and support when it comes to obtaining new innovative technology.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

56- The technical competence of staff should be considered before taking the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

57- Research and development capability of an organisation is required to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

58- BIM adoption requires the availability and effectiveness of human capability/resource for keeping the best people.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

59- BIM adoption requires intra-organisational management support.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

60- BIM adoption requires prior experience and IT expertise.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

61- It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

62- It was necessary to manage people who were resistant to change towards BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

63- The decision to adopt BIM is affected by the attitudes and perceptions (positive/negative) towards the type of innovation (BIM).

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

64- Social pressures are captured based on managers' perceptions rather than an actual understanding of the real world.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

65- It is necessary to maintain the championing image motives of a good using of advance technologies to facilitate the BIM adoption.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

66- Enabling environment of an organisation is required to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

67- BIM adoption requires organisational flexibility/ adaptability to market.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

68- Corporate management style (e.g. family owned or public owned) affects the decision to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

69- BIM adoption requires open discussion within an organisation.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

70- BIM adoption requires organisational restructuring.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

71- BIM adoption helps to achieve competitive advantages in the market.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

72- Our organisation has adopted BIM to acquire interest in our business.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

73- Our organisation has the need to innovate.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

74- The need for innovativeness is necessary to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

75- Before adopting BIM, our organisation had the interest to learn BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

76- The size of an organisation is positively related to its readiness to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

77- The number of company employees is positively related to its readiness to adopt BIM.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

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Final Section:

- Are you interested in receiving the result of this study? [If your answer is "Yes", please type your email below]

- Are you interested in participating in a short face-to-face (about 30 minutes in person or by Skype) with the researcher? [If your answer is "Yes", please type your email below]

- We would like to include further organisations in our study. Would you please recommend name(s)/contact(s) of other architectural organisations who have already adopted BIM.

Gratitude

We thank you very much for your kind contribution and support.

BACK

SUBMIT

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Appendix C

Table C.1 Summary results of the reliability of the sample size data

Communalities

Items	Initial	Extraction
1- Our main clients believe that we should use BIM	1.000	.748
2- Our trading partners put pressure upon us to use BIM	1.000	.788
3- We may not retain our important clients without BIM	1.000	.784
4- We have adopted BIM to respond to the BIM level 2 mandate by the UK government	1.000	.702
5- Non-adoption of BIM, may lead to contractual sanctions	1.000	.694
6- Our main competitors have adopted BIM and benefited from it	1.000	.764
7- Our main competitors who have adopted BIM are perceived favourably by clients	1.000	.807
8- Our main competitors who have adopted BIM are more competitive	1.000	.809
9- It is important to benchmark our BIM adoption against our main competitors	1.000	.673
10- Potential BIM adopters may imitate their main competitors‰?? implementations	1.000	.756
11- Potential BIM adopters imitate the behaviour of other firms within their network	1.000	.831
12- BIM has already been widely adopted by our clients	1.000	.746
13- BIM has been widely adopted by the architectural, engineering, and construction industry (AEC)	1.000	.616
14- The BIM norms, standards, and policies motivated and helped our organisation to adopt BIM	1.000	.730
15- BIM champions played a significant role in BIM diffusion	1.000	.687
16- The BIM external consultants influenced and facilitated our decision to adopt BIM	1.000	.678
17- Adopting BIM is perceived to improve the productivity of our organisation	1.000	.688
18- Adopting BIM is perceived to reduce overall cost	1.000	.763
19-Adopting BIM is perceived to shorten duration of a construction project	1.000	.706
20- Adopting BIM can mitigate risk	1.000	.682
21- Adopting BIM is perceived to improve task performance	1.000	.704
22- Adopting BIM is perceived to be advantageous in our organisation	1.000	.739
23- Adopting BIM is perceived to be compatible with existing processes in our organisation	1.000	.735
24- Adopting BIM is perceived to be compatible with our organisation culture and values	1.000	.801
25- Adopting BIM makes our work easier	1.000	.739
26- We adopted BIM because it is easy to learn	1.000	.763
27- Adopting BIM is perceived to improve collaboration in our organisation	1.000	.786
28- Adopting BIM is perceived to be too complex for business operations	1.000	.805
29- Trying out BIM features before adoption in practice provides the possibility of risk reduction	1.000	.753
30- We adopted BIM after a trial period	1.000	.709
31- The positive results of adopting and implementing BIM support its diffusion	1.000	.705
32- We adopted BIM as its positive effects were evident	1.000	.729
33- Our organisation has the intention to recommend BIM to others	1.000	.661
34- BIM interoperability across different platforms was key in the decision to adopt	1.000	.639
35- Adopting BIM is perceived to improve the visualisation of design effects	1.000	.729
36- The availability and affordability of BIM technology were key in the decision to adopt BIM	1.000	.756
37- The investment cost of BIM technology (software, hardware, training) did not affect our decision to adopt BIM.	1.000	.754
38- Our top management has the willingness to support change	1.000	.792
39- The general attitude of our organisation towards innovation facilitates the decision to adopt BIM.	1.000	.822
40- The senior management of our organisation encouraged the decision to adopt BIM.	1.000	.803

41- Our organisation has effective communication channels and networking within the architectural, engineering, and construction industry (AEC).	1.000	.810
42- Our organisation initiated a network of connections to know more about BIM when we first time had heard about it.	1.000	.784
43- Our organisation has direct communication with the early adopters of BIM.	1.000	.795
44- The internet/social media helped our organisation to understand more about BIM.	1.000	.791
45- Interpersonal channels helped our organisation to understand more about BIM.	1.000	.599
46- Our organisation has allocated a yearly budget for IT technologies that facilitated the decision to adopt BIM.	1.000	.649
47- The required cost to secure BIM was a key element in the decision to adopt.	1.000	.755
48- Our organisation perceived BIM as an affordable innovation.	1.000	.816
49- Our organisation has adopted BIM as its implementation cost was affordable.	1.000	.758
50- Our organisation has provided sufficient training to our staff as a preparation for BIM adoption.	1.000	.832
51- Our ability to adapt the technologies enabled us to adopt BIM.	1.000	.774
52- Our organisation has provided a professional BIM technology training.	1.000	.871
53- Technological capability of organisation is key to the decision to adopt BIM.	1.000	.709
54- Our organisation has employed experienced staff to adopt BIM.	1.000	.856
55- Our organisation has the capability of training and support when it comes to obtaining new innovative technology.	1.000	.738
56- The technical competence of staff should be considered before taking the decision to adopt BIM.	1.000	.771
57- Research and development capability of an organisation is required to adopt BIM.	1.000	.697
58- BIM adoption requires the availability and effectiveness of human capability/resource for keeping the best people.	1.000	.715
59- BIM adoption requires intra-organisational management support.	1.000	.645
60- BIM adoption requires prior experience and IT expertise	1.000	.642
61- It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption.	1.000	.847
62- It was necessary to manage people who were resistant to change towards BIM.	1.000	.584
63- The decision to adopt BIM is affected by the attitudes and perceptions (positive/negative) towards the type of innovation (BIM).	1.000	.776
64- Social pressures are captured based on managers‰?? perceptions rather than an actual understanding of the real world.	1.000	.733
65- It is necessary to maintain the championing image motives of a good using of advance technologies to facilitate the BIM adoption	1.000	.740
66- Enabling environment of an organisation is required to adopt BIM.	1.000	.804
67- BIM adoption requires organisational flexibility/adaptability to market.	1.000	.756
68- Corporate management style (e.g. family owned or public owned) affects the decision to adopt BIM.	1.000	.741
69- BIM adoption requires open discussion within an organisation.	1.000	.664
70- BIM adoption requires organisational restructuring.	1.000	.623
71- BIM adoption helps to achieve competitive advantages in the market.	1.000	.830
72- Our organisation has adopted BIM to acquire interest in our business.	1.000	.727
73- Our organisation has the need to innovate.	1.000	.558
74- The need for innovativeness is necessary to adopt BIM.	1.000	.705
75- Before adopting BIM, our organisation had the interest to learn BIM.	1.000	.784
76- The size of an organisation is positively related to its readiness to adopt BIM.	1.000	.892
77- The number of company employees is positively related to its readiness to adopt BIM.	1.000	.891

Table C.2 Summary results of the Normality of Data Distribution

Items	Skewness	Kurtosis
1- Our main clients believe that we should use BIM	-.690	-.134
2- Our trading partners put pressure upon us to use BIM	-.176	-.595
3- We may not retain our important clients without BIM	-.632	-.371
4- We have adopted BIM to respond to the BIM level 2 mandate by the UK government	-.449	-.528
5- Non-adoption of BIM, may lead to contractual sanctions	-.555	-.300
6- Our main competitors have adopted BIM and benefited from it	-1.282	2.180
7- Our main competitors who have adopted BIM are perceived favourably by clients	-.791	.677
8- Our main competitors who have adopted BIM are more competitive	-.570	-.142
9- It is important to benchmark our BIM adoption against our main competitors	-.724	.383
10- Potential BIM adopters may imitate their main competitors‰?? implementations	-.842	1.425
11- Potential BIM adopters imitate the behaviour of other firms within their network	-.645	.648
12- BIM has already been widely adopted by our clients	-.173	-.782
13- BIM has been widely adopted by the architectural, engineering, and construction industry (AEC)	-.386	-.415
14- The BIM norms, standards, and policies motivated and helped our organisation to adopt BIM	-.432	-.141
15- BIM champions played a significant role in BIM diffusion	-.805	.187
16- The BIM external consultants influenced and facilitated our decision to adopt BIM	-.137	-.660
17- Adopting BIM is perceived to improve the productivity of our organisation	-1.009	1.782
18- Adopting BIM is perceived to reduce overall cost	-.361	.083
19-Adopting BIM is perceived to shorten duration of a construction project	-.114	-.556
20- Adopting BIM can mitigate risk	-.758	.509
21- Adopting BIM is perceived to improve task performance	-.234	-.309
22- Adopting BIM is perceived to be advantageous in our organisation	-.467	.808
23- Adopting BIM is perceived to be compatible with existing processes in our organisation	-.585	-.474
24- Adopting BIM is perceived to be compatible with our organisation culture and values	-.714	-.172
25- Adopting BIM makes our work easier	-.611	-.314
26- We adopted BIM because it is easy to learn	-.562	-.441
27- Adopting BIM is perceived to improve collaboration in our organisation	-.879	.420
28- Adopting BIM is perceived to be too complex for business operations	-.688	-.110
29- Trying out BIM features before adoption in practice provides the possibility of risk reduction	-.848	1.003
30- We adopted BIM after a trial period	-.477	-.252
31- The positive results of adopting and implementing BIM support its diffusion	-.759	.895
32- We adopted BIM as its positive effects were evident	-1.033	1.499
33- Our organisation has the intention to recommend BIM to others	-1.284	2.031
34- BIM interoperability across different platforms was key in the decision to adopt	-.559	-.269
35- Adopting BIM is perceived to improve the visualisation of design effects	-.964	1.056
36- The availability and affordability of BIM technology were key in the decision to adopt BIM	-.595	-.136
37- The investment cost of BIM technology (software, hardware, training) did not affect our decision to adopt BIM.	-.631	.119
38- Our top management has the willingness to support change	-1.303	1.565
39- The general attitude of our organisation towards innovation facilitates the decision to adopt BIM.	-1.061	.833
40- The senior management of our organisation encouraged the decision to adopt BIM.	-.845	.061
41- Our organisation has effective communication channels and networking within the architectural, engineering, and construction industry (AEC).	-.995	.977
42- Our organisation initiated a network of connections to know more about BIM when we first time had heard about it.	-.684	-.268
43- Our organisation has direct communication with the early adopters of BIM.	-.751	-.012
44- The internet/social media helped our organisation to understand more about BIM.	-.728	-.044
45- Interpersonal channels helped our organisation to understand more about BIM.	-1.124	1.735
46- Our organisation has allocated a yearly budget for IT technologies that facilitated the decision to adopt BIM.	-.618	-.269
47- The required cost to secure BIM was a key element in the decision to adopt.	-.654	-.154
48- Our organisation perceived BIM as an affordable innovation.	-.476	-.370

49- Our organisation has adopted BIM as its implementation cost was affordable.	-.423	-.416
50- Our organisation has provided sufficient training to our staff as a preparation for BIM adoption.	-.718	.233
51- Our ability to adapt the technologies enabled us to adopt BIM.	-.984	1.242
52- Our organisation has provided a professional BIM technology training.	-.640	.084
53- Technological capability of organisation is key to the decision to adopt BIM.	-1.049	1.482
54- Our organisation has employed experienced staff to adopt BIM.	-.661	.131
55- Our organisation has the capability of training and support when it comes to obtaining new innovative technology.	-.681	.371
56- The technical competence of staff should be considered before taking the decision to adopt BIM.	-.940	.693
57- Research and development capability of an organisation is required to adopt BIM.	-.468	-.370
58- BIM adoption requires the availability and effectiveness of human capability/resource for keeping the best people.	-.924	1.749
59- BIM adoption requires intra-organisational management support.	-1.130	2.271
60- BIM adoption requires prior experience and IT expertise	-.474	-.515
61- It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption.	-1.284	2.875
62- It was necessary to manage people who were resistant to change towards BIM.	-1.070	1.851
63- The decision to adopt BIM is affected by the attitudes and perceptions (positive/negative) towards the type of innovation (BIM).	-1.210	2.561
64- Social pressures are captured based on managers‰?? perceptions rather than an actual understanding of the real world.	-1.155	2.163
65- It is necessary to maintain the championing image motives of a good using of advance technologies to facilitate the BIM adoption	-.813	1.548
66- Enabling environment of an organisation is required to adopt BIM.	-.645	1.661
67- BIM adoption requires organisational flexibility/adaptability to market.	-1.136	2.627
68- Corporate management style (e.g. family owned or public owned) affects the decision to adopt BIM.	-.548	1.322
69- BIM adoption requires open discussion within an organisation.	-1.283	2.632
70- BIM adoption requires organisational restructuring.	-.935	1.507
71- BIM adoption helps to achieve competitive advantages in the market.	-1.394	2.619
72- Our organisation has adopted BIM to acquire interest in our business.	-.739	.211
73- Our organisation has the need to innovate.	-.831	.324
74- The need for innovativeness is necessary to adopt BIM.	-.837	.639
75- Before adopting BIM, our organisation had the interest to learn BIM.	-.958	1.109
76- The size of an organisation is positively related to its readiness to adopt BIM.	-.437	-.709
77- The number of company employees is positively related to its readiness to adopt BIM.	-.467	-.796

Appendix D Second questionnaire (for the F-DEMATEL)

BIM Adoption by Architectural Organisations

I am a PhD Researcher at the School of Architecture within the University of Sheffield (UK), under the supervision of Professor Karim Hadjri and Associate Professor Dr Mohamad Kassem (Northumbria University).

My research aims to investigate the drivers and factors that influence Building Information Modelling (BIM) adoption process within architectural organisations.

If you have experience in the BIM adoption process within Architectural organisations (e.g. as internal or external change agents), we kindly invite to participate in this study. It approximately takes less than 12 minutes to complete this questionnaire.

The research is conducted in accordance with the Sheffield University policy on data storage and it has been ethically approved by the School of Architecture.

We greatly appreciate your support and we thank you for your contribution.

Ahmed L. Ahmed

Consent Form

1- I confirm that I have read and understand the information/invitation that explains the above research project.

2- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. In addition, should I not wish to answer any particular question or questions, I am free to decline.

3- I give permission for members of the research team to have access to my anonymised responses. I understand that my name and my organisation's affiliation will not be linked with the research materials, and will not be identified or identifiable in the report or reports that result from the research.

Please choose only one:

- ◯ I agree
- ◯ I disagree

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BIM Adoption by Architectural Organisations

Instructions for filling out the questionnaire

In the following sections, you will find BIM adoption factors organised in pairs. These pair relationship will be used to establish the potential influence of one factor on another.

Based on your experience and knowledge and after reading the explanation of the 11 factors, you are invited to determine the strength of the influence of factor X on factor Y using the following scale of five levels:

0 = No influence; 1 = Very low influence; 2 = Low influence; 3 = High influence; and 4= Very high influence

Example of filling the matrix

e.g.,
3 = High influence

Criteria	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1. Willingness/intention to adopt BIM	0										
F2. Communication behaviour of an organisation		0			3						
F3. Observability of BIM			0								
F4. Compatibility of BIM				0							
F5. Social motivations among organisation's members		0			0						
F6. Relative advantage of BIM						0					
F7. Organisational culture							0				
F8. Top management support								0			
F9. Organisational readiness									0		
F10. Coercive pressures (Governmental mandate, infromal mandate)										0	
F11. Organisation size (micro, small, medium, large)											0

e.g.,
0 = No influence

Definitions of the most influencing factors on the decision to adopt BIM

The below definitions present a brief idea about each of the factors:

F1. Willingness/intention to adopt BIM: refers to the favourable or unfavourable attitude of organisation or a decision-making unit towards the innovation/ BIM.

F2. Communication behaviour of an organisation: the degree of openness and engagement of an organisation with social groupings and networks interested in innovation adoption and promotion.

F3. Observability of BIM: the degree to which the results from innovation/BIM adoption are visible and tangible.

F4. Compatibility of BIM: the degree to which an innovation/BIM aligns with potential adopter's previous experiences and current needs and values.

F.5 Pro-social motivations among the organisation's members: the motivation to engage in behaviours that benefit others such as considering others' perspectives, stimulating knowledge exchange, and focusing on collective goals.

F.6 Relative advantage: the degree to which an innovation/BIM is perceived as being better than the system/practice it replaces.

F.7 Organizational culture: the shared norms, beliefs, principles, and traditions - held by the members of an organisational practice – which contribute to the members' understanding of the organisational functioning.

F8. Top management support: the degree to which senior management understands the importance of the innovation/BIM function and the extent to which they are involved into promoting the system adoption.

F9. Organisational readiness: the extent to which organisational members are psychologically and behaviourally prepared to implement a change, their mutual determination to perform the change, and their mutual faith in their aggregate capacity to achieve the change.

F10. Coercive pressures (e.g. government mandates and informal mandates): the formal and informal forces applied to organisations by other organisations (public and private clients/employers, etc.).

F11. Organisation size: the total number of full-time members of staff of an organisation (e.g., micro, small, medium, and large).

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1- Willingness to adopt BIM

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

1.1 Willingness to adopt BIM has an influence on the Communication behaviour of an organisation.

1.2 Willingness to adopt BIM has an influence on the Observability of BIM benefits.

1.3 Willingness to adopt BIM has an influence on the Compatibility of BIM.

1.4 Willingness to adopt BIM has an influence on the Social motivations among organisation's members.

1.5 Willingness to adopt BIM has an influence on the Relative advantage of BIM.

1.6 Willingness to adopt BIM has an influence on the Organisational culture.

1.7 Willingness to adopt BIM has an influence on Top management support.

1.8 Willingness to adopt BIM has an influence on the Organisational readiness.

1.9 Willingness to adopt BIM has an influence on the Coercive pressures.

1.10 Willingness to adopt BIM has an influence on the Organisation size.

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2- Communication behaviour of an organisation

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

2.1 Communication behaviour of an organisation has an influence on the Willingness to adopt BIM.

2.2 Communication behaviour of an organisation has an influence on the Observability of BIM benefits.

2.3 Communication behaviour of an organisation has an influence on the Compatibility of BIM.

2.4 Communication behaviour of an organisation has an influence on the Social motivations among organisation's members.

2.5 Communication behaviour of an organisation has an influence on the Relative advantage of BIM.

2.6 Communication behaviour of an organisation has an influence on the Organisational culture.

2.7 Communication behaviour of an organisation has an influence on the Top management support.

2.8 Communication behaviour of an organisation has an influence on the Organisational readiness.

2.9 Communication behaviour of an organisation has an influence on the Coercive pressures.

2.10 Communication behaviour of an organisation has an influence on the Organisation size.

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3- Observability of BIM

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

3.1 Observability of BIM benefits has an influence on the Willingness to adopt BIM.

3.2 Observability of BIM benefits has an influence on the Communication behaviour of an organisation.

3.3 Observability of BIM benefits has an influence on the Compatibility of BIM.

3.4 Observability of BIM benefits has an influence on the Social motivations among organisation's members.

3.5 Observability of BIM benefits has an influence on the Relative advantage of BIM.

3.6 Observability of BIM benefits has an influence on the Organisational culture.

3.7 Observability of BIM benefits has an influence on the Top management support.

3.8 Observability of BIM benefits has an influence on the Organisational readiness.

3.9 Observability of BIM benefits has an influence on the Coercive pressures.

3.10 Observability of BIM benefits has an influence on the Organisation size.

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4- Compatibility of BIM

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

4.1 Compatibility of BIM has an influence on the Willingness to adopt BIM.

4.2 Compatibility of BIM has an influence on the Communication behaviour of an organisation.

4.3 Compatibility of BIM has an influence on the Observability of BIM benefits.

4.4 Compatibility of BIM has an influence on the Social motivations among organisation's members.

4.5 Compatibility of BIM has an influence on the Relative advantage of BIM.

4.6 Compatibility of BIM has an influence on the Organisational culture.

4.7 Compatibility of BIM has an influence on the Top management support.

4.8 Compatibility of BIM has an influence on the Organisational readiness.

4.9 Compatibility of BIM has an influence on the Coercive pressures.

4.10 Compatibility of BIM has an influence on the Organisation size.

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5- Social motivations among organisation's members

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

5.1 Social motivations among organisation's members have an influence on the Willingness to adopt BIM.

5.2 Social motivations among organisation's members have an influence on the Communication behaviour of an organisation.

5.3 Social motivations among organisation's members have an influence on the Observability of BIM benefits.

5.4 Social motivations among organisation's members have an influence on the Compatibility of BIM.

5.5 Social motivations among organisation's members have an influence on the Relative advantage of BIM.

5.6 Social motivations among organisation's members have an influence on the Organisational culture.

5.7 Social motivations among organisation's members have an influence on the Top management support.

5.8 Social motivations among organisation's members have an influence on the Organisational readiness.

5.9 Social motivations among organisation's members have an influence on the Coercive pressures.

5.10 Social motivations among organisation's members have an influence on the Organisation size.

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6- Relative advantage of BIM

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

6.1 Relative advantage of BIM has an influence on the Willingness to adopt BIM.

6.2 Relative advantage of BIM has an influence on the Communication behaviour of an organisation.

6.3 Relative advantage of BIM has an influence on the Observability of BIM benefits.

6.4 Relative advantage of BIM has an influence on the Compatibility of BIM.

6.5 Relative advantage of BIM has an influence on the Social motivations among organisation's members.

6.6 Relative advantage of BIM has an influence on the Organisational culture.

6.7 Relative advantage of BIM has an influence on the Top management support.

6.8 Relative advantage of BIM has an influence on the Organisational readiness.

6.9 Relative advantage of BIM has an influence on the Coercive pressures.

6.10 Relative advantage of BIM has an influence on the Organisation size.

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7- Organisational culture

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

7.1 Organisational culture of BIM has an influence on the Willingness to adopt BIM.

7.2 Organisational culture of BIM has an influence on the Communication behaviour of an organisation.

7.3 Organisational culture of BIM has an influence on the Observability of BIM benefits.

7.4 Organisational culture of BIM has an influence on the Compatibility of BIM.

7.5 Organisational culture of BIM has an influence on the Social motivations among organisation's members.

7.6 Organisational culture of BIM has an influence on the Relative advantage of BIM.

7.7 Organisational culture of BIM has an influence on the Top management support.

7.8 Organisational culture of BIM has an influence on the Organisational readiness.

7.9 Organisational culture of BIM has an influence on the Coercive pressures.

7.10 Organisational culture of BIM has an influence on the Organisation size.

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8- Top management support

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

8.1 Top management support has an influence on the Willingness to adopt BIM.

8.2 Top management support has an influence on the Communication behaviour of an organisation.

8.3 Top management support has an influence on the Observability of BIM benefits.

8.4 Top management support has an influence on the Compatibility of BIM.

8.5 Top management support has an influence on the Social motivations among organisation's members.

8.6 Top management support has an influence on the Relative advantage of BIM.

8.7 Top management support has an influence on the Organisational culture.

8.8 Top management support has an influence on the Organisational readiness.

8.9 Top management support has an influence on the Coercive pressures.

8.10 Top management support has an influence on the Organisation size.

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9- Organisational readiness

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

9.1 Organisational readiness has an influence on the Willingness to adopt BIM.

9.2 Organisational readiness has an influence on the Communication behaviour of an organisation.

9.3 Organisational readiness has an influence on the Observability of BIM benefits.

9.4 Organisational readiness has an influence on the Compatibility of BIM.

9.5 Organisational readiness has an influence on the Social motivations among organisation's members.

9.6 Organisational readiness has an influence on the Relative advantage of BIM.

9.7 Organisational readiness has an influence on the Organisational culture.

9.8 Organisational readiness has an influence on the Top management support.

9.9 Organisational readiness has an influence on the Coercive pressures.

9.10 Organisational readiness has an influence on the Organisation size.

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10- Coercive pressures (Governmental and informal mandate)

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

10.1 Coercive pressures have an influence on the Willingness to adopt BIM.

10.2 Coercive pressures have an influence on the Communication behaviour of an organisation.

10.3 Coercive pressures have an influence on the Observability of BIM benefits.

10.4 Coercive pressures have an influence on the Compatibility of BIM.

10.5 Coercive pressures have an influence on the Social motivations among organisation's members.

10.6 Coercive pressures have an influence on the Relative advantage of BIM.

10.7 Coercive pressures have an influence on the Organisational culture.

10.8 Coercive pressures have an influence on the Top management support.

10.9 Coercive pressures have an influence on the Organisational readiness.

10.10 Coercive pressures have an influence on the Organisation size.

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11- Organisation size

No influence	Very low influence	Low influence	High influence	Very high influence
☐	☐	☐	☐	☐

11.1 Organisation size has an influence on the Willingness to adopt BIM.

11.2 Organisation size has an influence on the Communication behaviour of an organisation.

11.3 Organisation size has an influence on the Observability of BIM benefits.

11.4 Organisation size has an influence on the Compatibility of BIM.

11.5 Organisation size has an influence on the Social motivations among organisation's members.

11.6 Organisation size has an influence on the Relative advantage of BIM.

11.7 Organisation size has an influence on the Organisational culture.

11.8 Organisation size has an influence on the Top management support.

11.9 Organisation size has an influence on the Organisational readiness.

11.10 Organisation size has an influence on the Coercive pressures.

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Final Section: Basic personal data

Name
…………………………

Gender

Male ……………

Female…………

Job title
…………………………

Age
Choose:

Under 30 years old

30–40 years old

41–50 years old

Over 50 years old

- Please type your email if you are interested in receiving the result of this study.
…………………………

Gratitude

We thank you very much for your kind contribution and support.

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SUBMIT

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