Ahmed A. L., and Kassem, M. (2018). A unified BIM adoption taxonomy: Conceptual development, empirical validation and application, Automation in Construction, Vol. 96, pp. 103-127, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2018.08.017

A Unified BIM Adoption Taxonomy: Conceptual Development, Empirical Validation and Application

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Highlights:

1. Introduces and delineates key terms and concepts in the field of BIM adoption;
2. Establishes a Unified BIM Adoption Taxonomy of drivers and factors that affect the decision of organisations to adopt BIM;
3. Validates the Unified BIM Adoption Taxonomy using a Confirmatory Factor Analysis; and
4. Determines the factors affecting each stage of BIM adoption process within the UK Architectural sector using Ordinal Logistic Regression.

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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. Many studies have investigated the process of BIM adoption and diffusion and in particular, the drivers affecting adoption at different levels, ranging from individual and team through organisations and supply chains to whole market level. However, in-depth investigations of the stages of the BIM adoption process and the drivers, factors and determinants affecting such stages are still lacking. A comprehensive classification and integration of adoption drivers and factors is absent as these are disjointedly identified across disparate studies. There is also limited attention to the key terms and concepts (i.e. readiness, implementation, diffusion, adoption) in this area of study.

This aim in this paper is twofold: (1) to develop and validate a Unified BIM Adoption Taxonomy (UBAT); and (2) to identify the taxonomy's constructs (i.e. three driver clusters and their 17 factors) that have influence on the first three stages of the BIM adoption process namely, awareness, interest, and decision stages, and compare their effects on each of the stages. The research uses: a systematic literature review and knowledge synthesisation to develop the taxonomy; a confirmatory factor analysis for its validation; and an ordinal logistic regression to test the effect of the UBAT's constructs on the BIM adoption process within the UK Architectural sector using a sample of 177 organisations.

The paper is primarily intended to enhance the reader's understanding of the BIM adoption process and the constructs that influence its stages. The taxonomy and its sets of drivers and determinants can be used to perform various analyses of the BIM adoption process, delivering evidence and insights for decision makers within organisations and across whole market when formulating BIM diffusion strategies.

Keywords: BIM Adoption; BIM Diffusion; BIM Adoption Taxonomy; Innovation Diffusion Theory, Institutional Theory, Technology Acceptance Model.

1. Introduction

Construction is challenged more than ever with significant opportunities for innovation. Competitive pressures, digitalisation and automation, and owner demands for cost effectiveness and best value for money are key trends challenging the innovation status quo within the construction sector. Building Information Modelling (BIM) represents a significant opportunity to change the sector rigidness in attitudes toward change and innovation which have been hindering the modernisation of the construction sector. BIM is now considered as a key enabler of digital transformation that provide opportunities to harmonize the construction sector with emerging paradigms within our built environment such as the Internet of Things (IoT), smart sensors, connectivity and big data (Oesterreich and Teuteberg, 2016). To date, BIM is still one of most widely discussed innovations that have ever occurred in construction as evidenced from recent science mapping and bibliometric analyses of literature (Oraee et al., 2017, Santos et al., 2017, Zhao, 2017).

BIM is referred to as an expansive knowledge domain (Succar and Kassem, 2016), a "boundless" (Harty, 2005, p.51) or "systemic" innovation (Taylor and Levitt, 2004, p.84). BIM is causing concurrent evolutionary and revolutionary changes across several tiers ranging from individuals and groups, through organisations and project teams, to industries and whole markets (Succar, 2009b).

At macro market level, a number of studies have (1) identified the conceptual constructs of Macro-BIM adoption that can be used to assess 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 barriers 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 market (Seed, 2015).

Studies examining 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 BIM implementation motivations and the related project contextual factors (Cao et al., 2016).

Investigating BIM adoption at 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 innovation 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).

One key opportunity to enhance upon existing literature is to address the dispersion of BIM adoption drivers and factors and develop appropriate theoretical constructs that synthesise this important knowledge domain. To address this opportunity, this paper will develop and validate a Unified BIM Adoption Taxonomy, and demonstrate its application in investigating the process of BIM adoption by organisations within the UK architectural sector. To deliver this aim, the research questions that are used as a point of departure are:

- RQ1- what are the drivers and factors affecting BIM adoption by organisations within the construction industry?;
- RQ2- what are the theories, frameworks, and models adopted by scholars for examining BIM/innovation adoption and diffusion in construction?; and
- RQ3- How the results from addressing RQ1 and RQ2 above can be used to develop a new conceptual framework for investigating the effects of the taxonomy's constructs on the different phases of the BIM adoption process (i.e. awareness, interest, and adoption decision)?

The paper addresses in the following sections: clarification of key terms and concepts underpinning the BIM adoption domain; the systematic literature review and knowledge synthesisation process adopted to develop the taxonomy; the confirmatory factor analysis performed to validate the taxonomy's constructs and assess the reliability of measurements; the application of the taxonomy to analyse the BIM adoption process by organisations within the UK Architectural sector; and the theoretical implications and practical uses stemming from this study.

2. Key Terms and Concepts

This research investigates BIM adoption at organisational level while considering the pertinent market-wide aspects. Several of the terms used across this scale of investigation may have competing or complementary definitions. This section clarifies the position of this research in relation to these terms after briefly illustrating some of their existing interpretations:

- **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).

- **Adoption *vs.* Implementation *vs.* Diffusion**: 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 (Rogers, 2003), ‘adoption’ is one of the two outcomes (i.e. adoption, and rejection) of Stage 3 (i.e. decision stage). Succar and Kassem (2015) defines 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 (2016).
- **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).
- **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 organizational teams that are aggregated at a project level; and the *Micro cluster* includes individuals and groups at an organizational subdivision level.

3. Methodology and Research Methods

There seems to be a consensus among scholars that new knowledge can be created by building upon existing literature (Boell and Cecez-Kecmanovic, 2014, Jennex, 2015, Webster and Watson, 2002, King and He, 2005). This can be achieved by adapting existing theories, building new theories or synthesizing multiple theories (Cooper, 1998, Jackson, 1980, King and He, 2005, LePine and Wilcox-King, 2010, Okoli, 2012, Paré et al., 2015, Petticrew and Roberts, 2008, Randolph, 2009, Rowe, 2014, vom Brocke et al., 2015). However, the literature review must have certain properties in order to produce new knowledge. According to Schryen et al. (2015), there are three key properties: 1. *synthesis and interpretation* of existing literature through framing existing research in theory or identifying existing gap; 2. *focus on domain knowledge* as the realm of knowledge about a particular field, and 3. *Comprehensiveness* through the inclusion of representative and pivotal studies. To satisfy the three characteristics (i.e. synthesis and interpretation, focus on domain knowledge; and comprehensiveness), a systematic literature review approach was adopted. The systematic literature review aggregates the existing studies on a certain topic; provides clarification of potential inconsistencies; and validates existing research findings (King and He, 2005). It helps to minimise bias (systematic error); address clear research questions, and understand the reasons for heterogeneity between apparently similar studies (Kamal and Irani, 2014). Accumulating knowledge of several different but related studies is considered an efficient approach to achieve a generalised and comprehensive overview on a particular issue (Abdul Hameed, 2012). The systematic literature review also (1) helps to recognise gaps and suggest opportunities for future research, and (2) is considered a trustworthy, rigorous, and auditable methodology for collecting and combining existing research knowledge (Kitchenham and Charters, 2007).

Well-structured taxonomies allow "the meaningful clustering of experience" (Kwasnik, 1999, p.24) and are a means toward a number of different ends including the expansion generalisation of knowledge (Reisman, 1988, p.216). Research related to the construction sector generated several taxonomies. For example, Zuppa and Issa (2008) explored a taxonomy documenting the prioritized interests of stakeholders and aligning their interests; El-Diraby et al. (2005) presented a taxonomy for construction management; Sun and Meng (2009) developed taxonomies covering change causes and change effects in construction projects; (Garrett and Teizer, 2009) presented a taxonomy-enabled educational system for the classifying and analysing human errors affecting construction safety; (Wang and Dunston, 2011) developed a user centric classification of Mixed Reality (MR) approaches within the construction industry, and Kassem et al. (2015) proposed a taxonomy to organise the BIM knowledge contained within numerous noteworthy BIM publications. However, an extensive taxonomy of drivers and factors that influence the decision to adopt BIM by organisations is still lacking.

4. Systematic literature review (SLR): stages and implementation

Planning, execution and reporting are the three main phases of a SLR process (Kitchenham and Charters, 2007). Key steps across these three phases are: (1) formulating the review questions, (2) locating pertinent studies, (3) selecting and evaluating the identified studies, (4) analysing and synthesising, and (5) reporting the results (Denyer and Tranfield, 2009).

Phase I - Planning the review

The first two research questions (i.e. RQ1- what are the drivers and factors affecting the decision to adopt BIM by organisations within the construction industry?; and RQ2- what are the theories, frameworks, and models adopted by scholars for examining BIM/innovation adoption and diffusion in construction?) are formulated. The two questions will guide the design of the SRL protocols of Phase II.

Phase II - Executing the review

A range of search terms (Tables 1) and their synonyms are derived by decomposing RQ1 and RQ2. Boolean operators are used to guide the search within the databases (Table A1 in the Appendix). The returned studies are screened using the inclusion and exclusion criteria (Table A2) to ensure their relevance to the two research questions. A pilot search run was performed to further refine the selection criteria. A quality checklist (Table A3) (i.e., contribution, theoretical base, methodology, and analysis) is devised to ensure that the studies selected have an adequate methodological rigour. The studies identified are then subjected to data extraction and synthesis. In the data extraction stage, information extraction cards (i.e., structured tabular template) are used to systematically identify the key attributes from the identified studies and ensure comparability. An example of an information extraction card is included in Table A4 of the appendix. Finally, the findings and evidence in relation to each research question are collated at the data synthesis stage, which is explained in the extraction phase (Phase IV).

Table 1. Search terms

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	
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	

Phase III- Reporting the review results

The execution of the two search strings retrieved 3110 papers from across Scopus, ScienceDirect, Google Scholar, and Ethos in the primary search at stage one. This initial set of papers is screened and checked using a multi-stage process (Figure 1): removal of duplicate papers; checking titles and abstracts for relevance; checking papers against inclusion and exclusion criteria; and quality assessment. At the end of this process, 34 papers progressed to the data extraction stage. The assessment of papers against the quality criteria used a three-point scale: 'Y' (denoting 'Yes' with a score 1) for fully met quality criteria; 'P' (denoting 'Partially' with a score of 0.5) for partially met quality criteria, and 'N' (denoting No with a score of 0) for unmet quality criteria. The quality scores of the selected 34 papers is included in Table A5. The final set of selected papers for our study included papers that have at least one 'Yes' and no more than one 'No'.

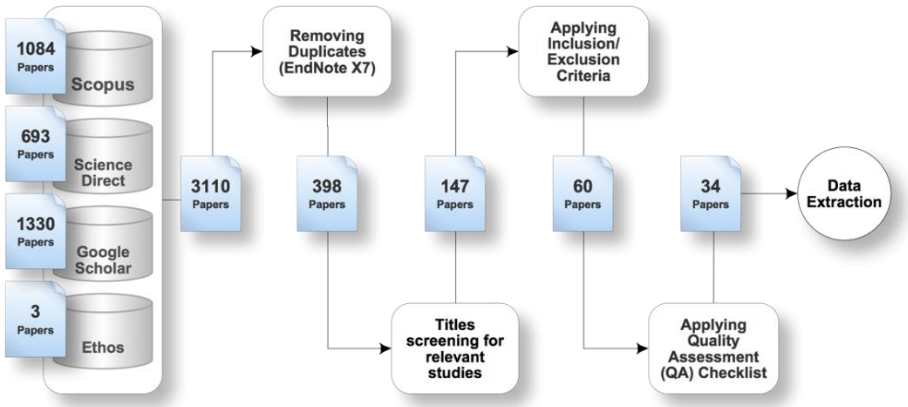


Figure 1: The SLR execution process

Phase IV- Extracting data from the selected papers

Data that were extracted from each study included: the demographic information such as title, authors, publishing body, journal/conference, publishing year, and country of the study; the innovation being investigated (i.e., BIM or IS); the targeted organisational scale considered (i.e., market, organisation, supply chain, or project); the research design, data collection and analysis methods; the adopted theories, frameworks and models of BIM/innovation adoption; and the findings (i.e. the identified drivers and factors influencing BIM/innovation adoption). Table A6 and A7 summarise some of the key data relevant to this study.

All the 34 (100%) identified studies addressed RQ1 by achieving either a full 'Y' score or a partial 'P' score resulting in an overall score of 72%. RQ2 was addressed fully (i.e. sore of 1) by 28 (82%) studies, partially (i.e. score of 0.5) by two studies and not addressed (i.e. score of 0) by six studies, resulting in an average score of 79%. The drivers, factors and determinants captured from across these 34 studies (RQ1) will be united with the results from addressing RQ2 to develop the BIM adoption taxonomy.

Table A7 summarises the results for RQ2 from across the 34 studies. 26 (76%) studies adopted theoretical standpoints to analyse the process of IS / BIM adoption. The theories adopted included: Innovation Diffusion Theory (IDT) (53%), Institutional Theory (INT) (26%), Technology Acceptance Model (TAM) (21%), mixed-theories (21%), and Theory of Reasoned Action (TRA) (6%).

The Innovation Diffusion Theory (IDT) proposes five elements to describe the characteristics of an innovation: relative advantage, compatibility, complexity, trialability, and observability. It explains the characteristics of an adopter (i.e., characteristics of an individual or the decision-making unit) in terms of socioeconomic characteristics, personality variables, and communication behaviour (Rogers, 2003, p.282). The IDT suggests a five-stage model of 'innovation-decision process', which includes awareness, interest, decision, implementation, and confirmation (Rogers, 2003, p.169).

The Technology Acceptance Model (TAM) seeks to predict users' acceptance of a technological innovation and explains the behaviour of individuals against IT acceptance (Hameed et al., 2012) . The TAM identifies two factors as determinants for the use of a new system: perceived ease of use, and perceived usefulness (Davis, 1989). It establishes theoretical linkages among beliefs, intention, and action to explain a system use: the user's belief (i.e., perceived ease of use, and perceived usefulness) about a given system influences the user's behaviour and intention to use the system, which in turn, determines its actual use.

The Institutional Theory (INT) suggests diffusion dynamics in which external isomorphic pressures motivate organisations to perform behavioural and structural changes while seeking to acquire social legitimacy (DiMaggio and Powell, 1983). The institutional pressures include: coercive, mimetic, and normative pressures (DiMaggio and Powell, 1983, Fareed et al., 2015). Organisations comply with formal pressures (mandates, regulations), mimic successful practices, or conform to informal restrictions (i.e., beliefs, norms, and conventions). The institutional legitimacy is determined by the organisations' response towards these pressures.

The review shows that the simultaneous use of the Innovation Diffusion Theory (IDT) and Institutional Theory (INT) in investigating the decisions to adopt BIM by organisations is limited. Only five papers [i.e., (Succar and Kassem, 2015); (Tsai et al., 2013); (Henderson et al., 2012); (Cao et al., 2016); and (Ahuja et al., 2016)] included to a varying degree aspects from the two theories. For example, in (Succar and Kassem, 2015) the two theories are mentioned but their use aimed to clarify and demarcate the key terms and concepts for the purpose of developing new constructs for macro BIM adoption. Both (Tsai et al., 2013) and (Henderson et al., 2012) mainly embraced constructs from the INT (i.e. isomorphic pressures) combined with a marginal use of IDT aspects to investigate BIM adoption. (Cao et al., 2016) and (Ahuja et al., 2016) focused on a few selected aspects from the IDT (i.e., control variables and economic motivations in [Cao et al., 2016]; technology innovation and top management support in [Ahuja et al., 2016]) and the INT (i.e., social motivations in [Cao et al., 2016], and client support and trading partner in [Ahuja et al., 2016]). This shows that drivers and factors affecting the decision to adopt BIM/innovation by organisations are dispersed among different studies as a result of the specific theoretical lens adopted by scholars. The proposed taxonomy will address this limitation by including an extensive set of BIM adoption drivers, factors and determinants. It will also contribute to addressing some of the emerging research questions in the area of BIM adoption at both organisational and market level as evidenced in this paper.

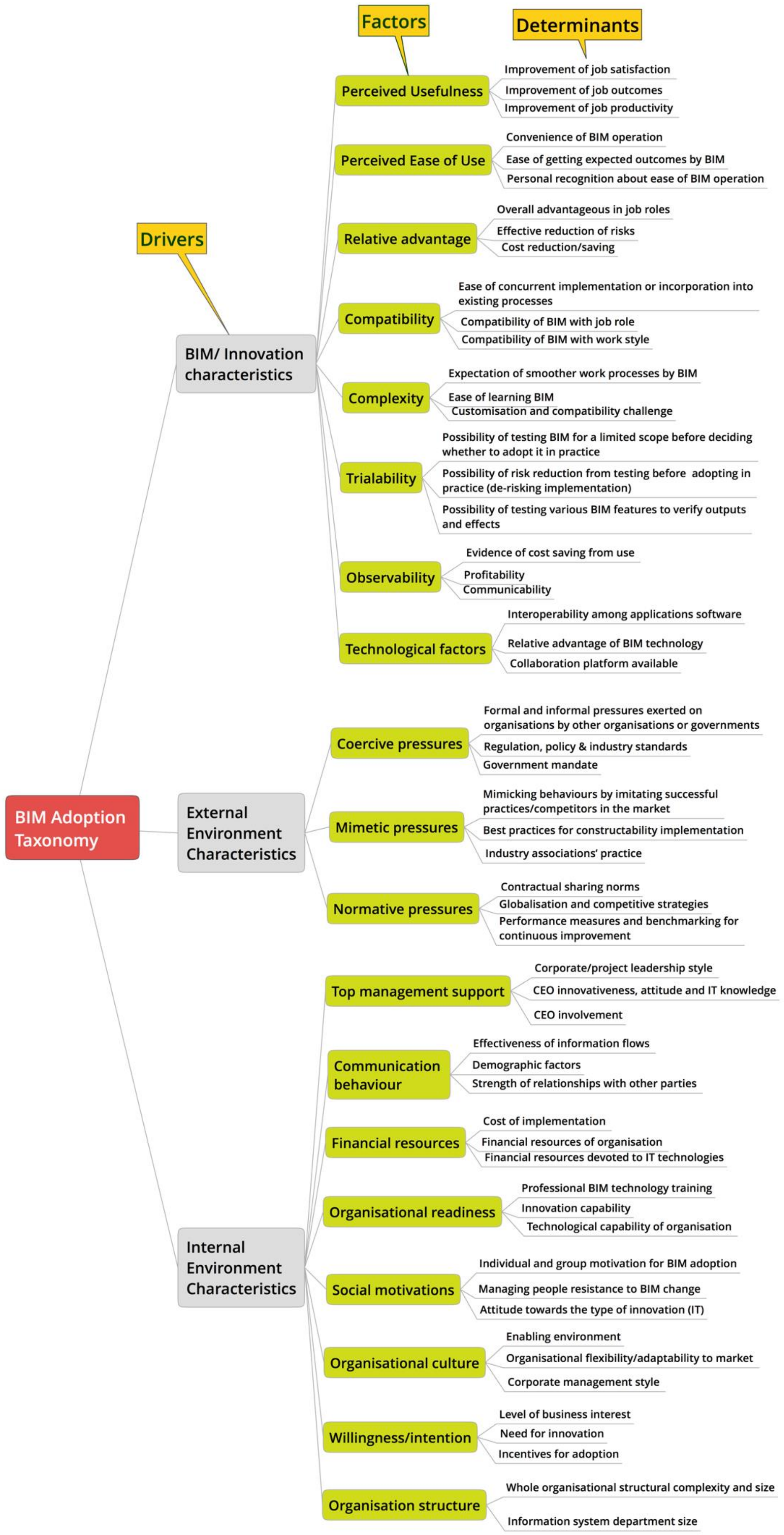
5. The BIM Adoption Taxonomy

The BIM adoption taxonomy emerged as a result of our investigation of RQ1 (i.e. what are the drivers and factors affecting the decision to adopt BIM at organisation level within the construction industry?) (Table A8); 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 (Figure 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 *BIM innovation characteristics*, include factors such as relative advantage; compatibility; complexity; trialability; observability (Tsai et al., 2013, Rogers, 2003); perceived ease of use, and perceived usefulness (Ramanayaka and Venkatachalam, 2015). The relative advantage is "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 2003, p.229). Compatibility reflects the "consistency of the innovation with existing values, past experiences and needs of potential adopters" (Rogers, 2003, p.240). Complexity, is "the degree to which an innovation is perceived as difficult to understand and use"(Rogers, 2003, p.257). Trialability is "a measure of the availability of the innovation to potential adopters for trial periods". Observability measures "the degree to which the results on an innovation are visible to others" (Rogers, 2003, p.258). The perceived ease of use is "the degree to which a person believes that using a particular system will be effortless" (Davis, 1989, p.320). There is an apparent similarity between the 'complexity' construct within IDT and the 'perceived ease of use' in TAM as they often complement each other (Xu et al., 2014). However, 'Complexity' involves the formation of favourable or unfavourable attitudes towards an innovation before the decision to adopt is made (Abdul Hameed, 2012, Xu et al., 2014), while 'perceived ease of use' is a determinant of actual system use (implementation) at the implementation stage after the decision to adopt has been made (Xu et al., 2014). The perceived usefulness indicate the adopter's belief that using a particular system will enhance job performance (Davis, 1989, p.320). The technological factors includes factors such as interoperability, compatibility, cost and the relative advantages associated with the use of the innovation (Waarts et al., 2002) (Table A9).

The internal environment characteristics of a decision unit or an organisation include factors such as: top management support, communication behaviour, financial resources and perceived cost, organizational readiness, social motivations, organisational culture, willingness/intention, and organisation size (Peansupap and Walker, 2005, Tsai et al., 2010, Cao et al., 2014). The top management support represents their attitude towards promoting and supporting internal motivations to actively embrace innovative technologies such as BIM (Xu et al., 2014). The communication behaviour represents the effectiveness of information flows (i.e., communication flows) within an organisation and affect the strength of relationships with other parties (Mom et al., 2014). Financial resources and Perceived cost include a range of economic factors related to the implementation of the BIM innovation within organisations and projects (Mom et al., 2014, Waarts et al., 2002). The Organisational readiness is the pre-implementation status representing the propensity of an organisation or organisational unit to adopt BIM tools, workflows and protocols (Succar and Kassem, 2015). Readiness describes the level of preparation, the potential to participate, or the capacity to innovate (Succar and Kassem, 2015, p.65). Social motivations include a range of determinants that can be affected by social interactions such as the attitude and perceptions of both individuals and groups with regards to BIM adoption.



313 Figure 2: The BIM Adoption Taxonomy

The *organisational culture* brings adoption determinants such as the willingness to restructure or reengineer processes; the corporate management style; the learning and growth perspective; the openness of discussions; and the availability of support for individual and group during the transition (Abubakar et al., 2014); (Mom et al., 2014); (Peansupap and Walker, 2005).

The identified determinants related to the organisational *Willingness/intention* include the level of business interest in BIM innovation (Gu and London, 2010), the need for BIM personnel and training (Mom et al., 2014), the need for innovation (Singh and Holmstrom, 2015), organisations' individual enjoyment with innovation (Talukder, 2012), and the organisational competitive advantages (Gu and London, 2010, Rogers et al., 2015). Finally, the organisational size determinants include the size of the whole organisation, the size of its information system department, and the organisational complexity (Hameed et al., 2012) (Table A10).

The *external environment characteristics* affects innovation adoption through isomorphic pressures; competitive and institutional (Mizruchi and Fein, 1999, DiMaggio and Powell, 1983). Competitive pressures involve pressures toward similarity resulting from market competition (e.g., supply and demand dynamics) (Oliveira et al., 2014, Yitmen, 2007). Institutional isomorphic pressures – which include coercive pressures; mimetic pressures; normative pressures – involve "organisational competition for political and institutional legitimacy as well as market position" (Mizruchi and Fein, 1999, p. 657). *Coercive pressures* emerge from political effect and legitimacy issues (DiMaggio and Powell, 1983). These effects might be formal (e.g. a market BIM mandate, regulatory requirement) and informal pressures applied on organisations by other organisations upon which they are dependent (Teo et al., 2003). These informal pressures could be sensed as forces, persuasion, or as offers to join in alliances. *Mimetic pressures* emerge 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 either forms: by imitating competitors who have achieved successful adoption of an innovation, or based on the rate of an innovation adoption (i.e. proportion of adoption in the social system reaches the social threshold) in the industry where the organisation operates (Teo et al., 2003). This process is also called social learning (DiMaggio and Powell, 1983) and is based on the bandwagon effect (Son and Benbasat, 2007). Due to the similarity between the competitive pressures and mimetic pressures, their effect is substituted with mimetic pressures. *Normative pressures* stem from common norms and shared values that are related to professionalization and relations with organisations (DiMaggio and Powell, 1983, Teo et al., 2003). Therefore, an organisation adopts an innovation to either, comply with formal *coercive* pressures (mandates, regulations), mimic successful prior adopters, or conform to informal restrictions (i.e., beliefs, norms, and conventions). The response to these pressures determines the organisation institutional legitimacy (Table A11).

The BIM adoption taxonomy in Figure 2 includes a non-extensive list of determinants (Level 3 of the taxonomy). An extensive list of determinants across the three driver clusters and their factors is included in the appendix in Tables A9, A10 and A11.

6. Validity and reliability of the taxonomy

The testing of the validity and reliability of the taxonomy was performed using confirmatory factor analysis. To attain the required data for the testing, a survey approach was adopted using an online structured questionnaire. 509 organisations were invited to participate in the data collection campaign. 177 valid responses were returned and 6 incomplete responses were discarded resulting in response rate of 36%. The targeted organisations are listed within the Royal Institute of British Architects (RIBA) as organisations offering BIM services. The selected respondent representing each organisation is an individual who was either involved in or knowledgeable about the process that led their organisation to adopt BIM. Such individuals assumed positions such as directors, partners and BIM managers. Following their consent which was obtained either during a phone call or direct messaging via LinkedIn, they were invited to submit their responses using an online survey tool. The data collection campaign started in mid-January 2017 and concluded in August 2017.

The questionnaire included two sections: the first section aimed to collect demographic information (i.e. organisation size, number of BIM projects, and dates/timing of decisions to adopt BIM); the second section included 77 statements covering the 20 taxonomy's constructs (20 clusters of factors under the three drivers (i.e. BIM Innovation characteristics; External Environment characteristics, and Internal Environment characteristics). Table A12 contains a sample of the statements included in the questionnaire. A five-point Likert scale - ranging from 'strongly disagree' to 'strongly agree' - was used to measure the respondents' level of agreement with the various statements that represents the measurement items of the taxonomy's constructs (e.g. drivers and their corresponding factors).

Measurement models and their structural equation models

A Confirmatory Factor Analysis (CFA) was performed to evaluate and validate the measurement models that represented the taxonomy's constructs in the form of structural equation Models (SEM). 17 out of the 19 constructs were tested. Two constructs (i.e., perceived usefulness; and perceived ease of use under the BIM innovation characteristics) were excluded from the measurement models since their effect, according to the innovation adoption literature (Davis, 1989, Abdul Hameed, 2012, Xu et al., 2014), unfold at the implementation stage after the adoption decision has been made (i.e. in implementation Stage, Stage IV in Rogers's Innovation-Decision Process), while the survey questions were focussed on analysing the adoption process up to decision stage. 17 constructs pertinent to three BIM adoption drivers (i.e. external environment characteristics, innovation characteristics, and internal environment characteristics) were validated. These included: three constructs (i.e. coercive pressures, mimetic pressures, and normative pressures) associated with the external environment characteristics; six constructs (i.e. relative advantage, compatibility, complexity, trialability, observability, and technological factors) with the innovation characteristics; and eight constructs (i.e. top management support, communication behaviour, financial resources, organisational readiness, social motivations, organisational culture, willingness/intention, and organisation size) with the internal environment characteristics. Three CFA measurement models are developed and tested in the next section.

Goodness-of-fit

Due the significant number of the observed items (i.e., 77 questionnaire items) compared to the number of obtained observations (i.e., 177 responses), this study conducted three individual CFA models, one for each construct: the external environment characteristics, the innovation characteristics, and the internal environment characteristics. This approach of testing a whole construct through its components or sub-parts is commonly used in literature (AL-Sabawy, 2013, Paiva et al., 2008) .

The models were built in SPSS AMOS 24 and evaluated through five 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). The criteria of cut-off of these five fitness indices are listed in Table 3. Prior to assessing the First-order factor analysis of each BIM adoption driver, One-factor congeneric measurement model of each construct (i.e., BIM adoption factor) was performed to measure the goodness-of-fit of these constructs:

- Some constructs including coercive pressures, complexity, observability, and technological factors, top management support, and organisational culture showed very good fit at the first iteration; while
- Other constructs such as mimetic pressures, normative pressures, relative advantage, communication behaviour, financial resources, organisational readiness, social motivations, and willingness/intention improved after a few iterations by eliminating the non-significant items.

The CFA models of both the *external environment* characteristics driver (Figure A1) and the *innovation* characteristics driver (Figure A2) were assessed using First-order *BIM* factor analysis and have showed a very good fit with the model by having all their respective indices [i.e. (*external environment* characteristics: CMIN/DF= 1.979; CFI= 0.931; RMR= 0.0632; RMSEA= 0.075; PCLOSE= 0.014); (i.e. *innovation* characteristics driver: CMIN/DF= 1.815; CFI= 0.909; RMR= 0.0611; RMSEA= 0.068; PCLOSE= 0.011)] within the acceptable thresholds.

The measurement model for the *internal environment* characteristics driver required four iterations to achieve a very good fit. The iterations were done by identifying and eliminating the non-significant items. The results at the final iteration were: CMIN/DF= 1.424; CFI= 0.518; RMR= 0.0811; RMSEA= 0.049; PCLOSE= 0.570, and demonstrated a very good fit (Figure A3 of the Appendix).

Table 3. 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

Validity Assessment

The three CFA measurement models were evaluated for validity and reliability. Three types of validity were tested:

- *Convergent validity:* it evaluates relationships between the observed variables and the constructs (Schumacker and Lomax, 2004). It was tested on the basis 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). The factor loadings for all the 17 constructs were acceptable values, ranging from 0.588 to 0.940 (Table 4).
- *Discriminant validity:* It can be used to assess whether the results confirming the hypothesised structural paths are real or are the product of statistical discrepancies (Farrell, 2010). It was tested by assessing the square root of Average Variance Extracted (AVE) of each construct and comparing it with the correlation value of the same construct with others. For a construct to be valid, its AVE value must exceed its correlation value with others constructs (Chin, 1998, Guo et al., 2011). A construct is more likely to be strongly correlated with its indicators than with the other constructs in the model when the square roots of the AVE value is greater than the absolute values of the off-diagonal correlations in the corresponding rows and columns of the correlation matrix. All the 17 constructs satisfied this rule (Tables 6, 7, and 8) proving their discriminant validity.
- *Construct validity:* It is a combination of the convergent validity and discriminant validity and it is a necessary condition for theory development and testing (Gefen and Straub, 2005). It was tested using the goodness-of-fit of the indices of the three CFA measurement models which was confirmed as shown in Table 5 for all the 17 constructs.

Reliability Assessment

The reliability of the measurement for each of the 17 constructs was tested using four indicators: Squared Multiple Correlation (SMC) ‘item reliability’; Cronbach's alpha; Construct Reliability (composite reliability) (CR); and Average Variance Extracted (AVE).

The minimum acceptable SMC value of the observed variables is 0.30 and values exceeding 0.50 indicate good reliability (Holmes-Smith, 2011). The SMC value obtained for the tested 17 constructs (Table 4) varied between 0.346 to 0.885 which demonstrates the reliability of the constructs and their corresponding three models (i.e. drivers).

The reliability of the *internal consistency* was tested using the Cronbach's alpha. The value of this indicator for a reliable internally-consistent model is 0.70 or higher (Hair et al., 2016, Nunnally and Bernstein, 1994). The Cronbach's alpha of the 17 constructs (Table 4) have all exceeded the minimum threshold by scoring between 0.768 and 0.921 and therefore, confirming the reliability of the models.

Construct Reliability (CR) was also used to test the reliability of the *internal consistency* by measuring the level of Coefficient H (Hancock and Mueller, 2001). The acceptable minimum threshold of Coefficient H is 0.70. All the resulting CR values of the constructs have exceeded 0.70 (Table 4) indicating a high level of reliability.

Average Variance Extracted (AVE) was also applied to assess the reliability of constructs. The score achieved for all the constructs, with the exception of 'Technological factors', have exceeded the acceptable minimum threshold of 0.50. However, since the AVE value for 'Technological factors' (i.e. 0.452) is very close to the acceptable level of 0.50 and all other reliability indicators (i.e., Cronbach's alpha, Coefficient H, and construct reliability) were higher than their corresponding acceptable levels, the reliability of the 'Technological factors' construct can be supported (Table 4).

All these tests together confirm that (1) the performed measurements to evaluate the constructs of the BIM adoption drivers are valid; and (2) the instruments used and the data collected are reliable. Therefore, it can be concluded that the validation of the proposed BIM adoption taxonomy was achieved.

Table 4. Results of the three CFA measurement models

Construct	Item retained	Factor loading	p-value	S.M.C (R^2)	(C.R.)	AVE	Cronbach's Alpha
Coercive pressures	XA_Q1	.771	***	.595	.836	.508	.836
	XA_Q2	.762	***	.580			
	XA_Q3	.776	***	.602			
	XA_Q4	.598	***	.357			
	XA_Q5	.637		.406			
Mimetic pressures	XB_Q6	.771	***	.594	.846	.582	.843
	XB_Q7	.835	***	.697			
	XB_Q8	.806	***	.649			
	XB_Q9	.621		.385			
Normative pressures	XC_Q12	.754	***	.569	.837	.508	.839
	XC_Q13	.701	***	.491			
	XC_Q14	.707	***	.500			
	XC_Q15	.706	***	.499			
	XC_Q16	.693		.481			
Relative advantage	YA_Q17	.733	***	.538	.835	.503	.806
	YA_Q18	.755	***	.570			
	YA_Q20	.646	***	.418			
	YA_Q21	.732	***	.536			
	YA_Q22	.675		.455			
Compatibility	YB_Q23	.800	***	.640	.798	.664	.798
	YB_Q24	.829		.688			
Complexity	YC_Q25	.781	***	.611	.876	.639	.877
	YC_Q26	.767	***	.588			
	YC_Q27	.860	***	.740			
	YC_Q28	.787		.620			
Trialability	YD_Q29	.784	***	.615	.719	.562	.717
	YD_Q30	.714	***	.510			
Observability	YE_Q31	.642	***	.412	.781	.545	.774
	YE_Q32	.799	***	.638			
	YE_Q33	.765		.586			
Technological factors	YF_Q34	.647	***	.419	.766	.452	.768
	YF_Q35	.782	***	.611			
	YF_Q36	.658	***	.433			
	YF_Q37	.588		.346			
Top management support	ZA_Q38	.832	***	.693	.893	.735	.890
	ZA_Q39	.873	***	.762			

	ZA_Q40	.866		.750			
Communication behaviour	ZB_Q41	.836	***	.699	.891	.672	.880
	ZB_Q42	.867	***	.751			
	ZB_Q43	.839	***	.704			
	ZB_Q44	.731		.535			
Financial resources	ZC_Q47	.705	***	.497	.776	.536	.835
	ZC_Q48	.757	***	.574			
	ZC_Q49	.734		.539			
Organisational readiness	ZD_Q50	.919	***	.845	.905	.705	.858
	ZD_Q52	.897	***	.805			
	ZD_Q54	.807		.651			
	ZD_Q55	.722		.521			
Social motivations	ZE_Q61	.806	***	.650	.812	.591	.870
	ZE_Q63	.788	***	.620			
	ZE_Q65	.709		.502			
Organisational culture	ZF_Q66	.802	***	.643	.890	.618	.841
	ZF_Q67	.796	***	.633			
	ZF_Q68	.746	***	.556			
	ZF_Q69	.808		.653			
	ZF_Q70	.778		.605			
Willingness/intention	ZG_Q71	.815	***	.664	.850	.587	.825
	ZG_Q72	.777	***	.604			
	ZG_Q74	.714	***	.510			
	ZG_Q75	.754		.568			
Organisation size	ZH_Q76	.940	***	.885	.911	.836	.921
	ZH_Q77	.888		.789			

**** = 0.001; S.M.C (Squared Multiple Correlation); AVE: (Average variance extracted); C.R: (Composite reliability)*

Table 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	1.815	0.909	0.0611	0.068	0.011
Internal environment characteristics	1.424	0.518	0.0811	0.049	0.570

Table 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 8. Inter-correlation matrix of discriminant validity for the internal environment characteristics

Construct	1	2	3	4	5	6	7	8
1- Top management support	**0.857**							
2- Communication behaviour	0.504	**0.820**						
3- Financial resources	0.418	0.416	**0.732**					
4- Organisational readiness	0.300	0.454	0.458	**0.840**				
5- Social motivations	0.152	0.184	0.262	0.519	**0.769**			
6- Organisational culture	0.142	0.081	0.193	0.447	0.618	**0.786**		
7- Willingness /intention	0.235	0.261	0.174	0.350	0.456	0.546	**0.766**	
8- Organisation size	0.046	-0.127	-0.063	0.228	0.223	0.334	0.202	**0.914**

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

Table 7. Inter-correlation matrix of discriminant validity for the innovation characteristics

Constructs	Relative advantage	Compatibility	Complexity	Trialability	Observability	Technological factors
Relative advantage	**0.709**					
Compatibility	0.379	**0.815**				
Complexity	0.454	0.077	**0.800**			
Trialability	0.212	-0.057	0.138	**0.750**		
Observability	0.661	0.333	0.400	0.280	**0.738**	
Compatibility	0.350	0.057	0.249	0.315	0.554	**0.672**

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

7. Use of the taxonomy to investigate BIM adoption within the UK

Conceptual model

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) theories (Figure 3).

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). The interactions between the constructs from the IDT and INT on the adoption process are illustrated in Figure 3. 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.

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).

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.

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.

Due to the peculiarities of BIM being an innovation entailing multiple capabilities stages [i.e. modelling, collaboration, and integration as established by (Succar, 2009a)], 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.

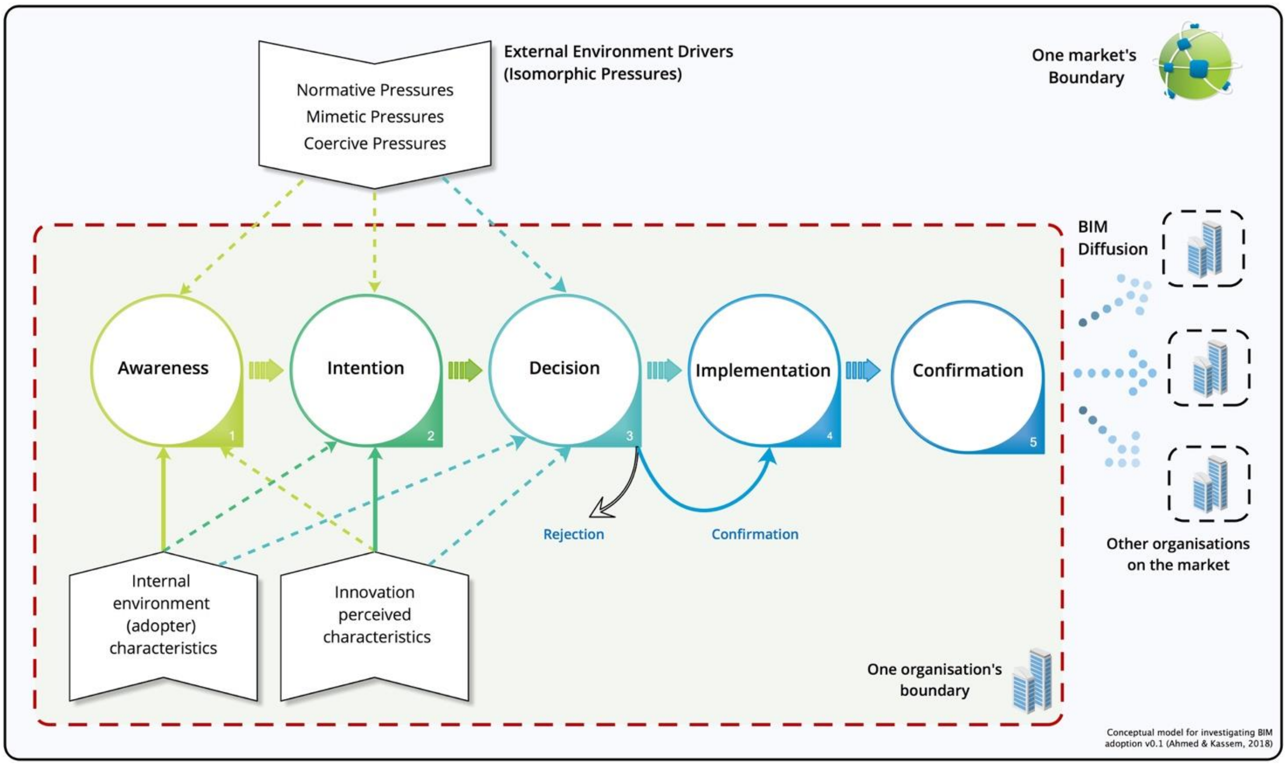


Figure 3: Conceptual Model for investigating BIM adoption decisions [adapted from Rogers's (2003)]

Hypotheses Formulation and Testing

51 (i.e. 17 constructs x 3 adoption stages) hypotheses were formulated by postulating relationship effects between each of 17 factors of the driver clusters (i.e. *external environment characteristics, innovation characteristics, and internal environment characteristics)* and the three adoption stages (i.e., *awareness*, *intention*, and *decision*). Table 9 shows a sample of hypotheses related to the potential influence of the external's environment drivers on the three adoption stages. Ordinal Logistic Regression analysis was employed to test the hypotheses. The aim is to provide a granular investigation of BIM adoption not only through identification the factors that affect each adoption stage, but also through ranking the effect of influencing factors at each stage. These two result types are illustrated in Figure 4. The Figure also includes the 22 hypotheses that entailed factors with positive and significant influence on the adoption stages. 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).

The '**Awareness**' stage is influenced by six factors associated with the organisational internal environment characteristics and the BIM innovation characteristics. These factors are: *Willingness/intention, 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/drivers* (i.e., institutional pressures) had no significant effect on the awareness.

The '**Intention'** stage was found to be affected 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. Similarly to the intention stage, only coercive pressures had a positive and significant influence on the decision to adopt BIM by architectural organisations.

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 – even those that were not found to have significant and positive influence - at each stage of the adoption process can result in new influences and dynamics. These interplays will be captured through correlation analysis in future extension of this work.

The results illustrated in Figure 4 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., $\leq$0.05) and highest 'Estimate' value of the results of Ordinal Logistic Regression test. Willingness is the factor with the highest influence on the Awareness stage. *Communication behaviour has the highest influence on both the Intention stage and Decision stage.* Communication behaviour represents the effectiveness of information flows (i.e., communication flows) within an organisation and affect the strength of relationships with other parties (Mom et al., 2014). It can be either formal or intra-organisational communication (e.g., working colleagues interacting within the same organisation unit), or informal and inter-organisational communication (e.g., like-minded individuals from different organisations sharing good practices for their individual mutual advantage) (Murray et al., 2007).

Table 9. Hypotheses about effects of external environment's factors on adoption stages

Factors	**Code**	**Hypotheses**
Coercive pressures	H1	Architectural organisations which are subjected to coercive pressures are more likely to be aware of BIM.
	H2	Architectural organisations which are subjected to coercive pressures are more likely to develop interest in adopting BIM.
	H3	Architectural organisations which are subjected to coercive pressures are more likely to make the decision to adopt BIM.
Mimetic pressures	H4	Architectural organisations which are subjected to mimetic pressures are more likely to be aware of BIM.
	H5	Architectural organisations which are subjected to mimetic pressures are more likely to develop interest in adopting BIM.
	H6	Architectural organisations which are subjected to mimetic pressures are more likely to make the decision to adopt BIM.
Normative pressures	H7	Architectural organisations which are subjected to normative pressures are more likely to be aware of BIM.
	H8	Architectural organisations which are subjected to normative pressures are are more likely to develop interest in adopting
	H9	Architectural organisations which are subjected to normative pressures are more likely to make the decision to adopt BIM.

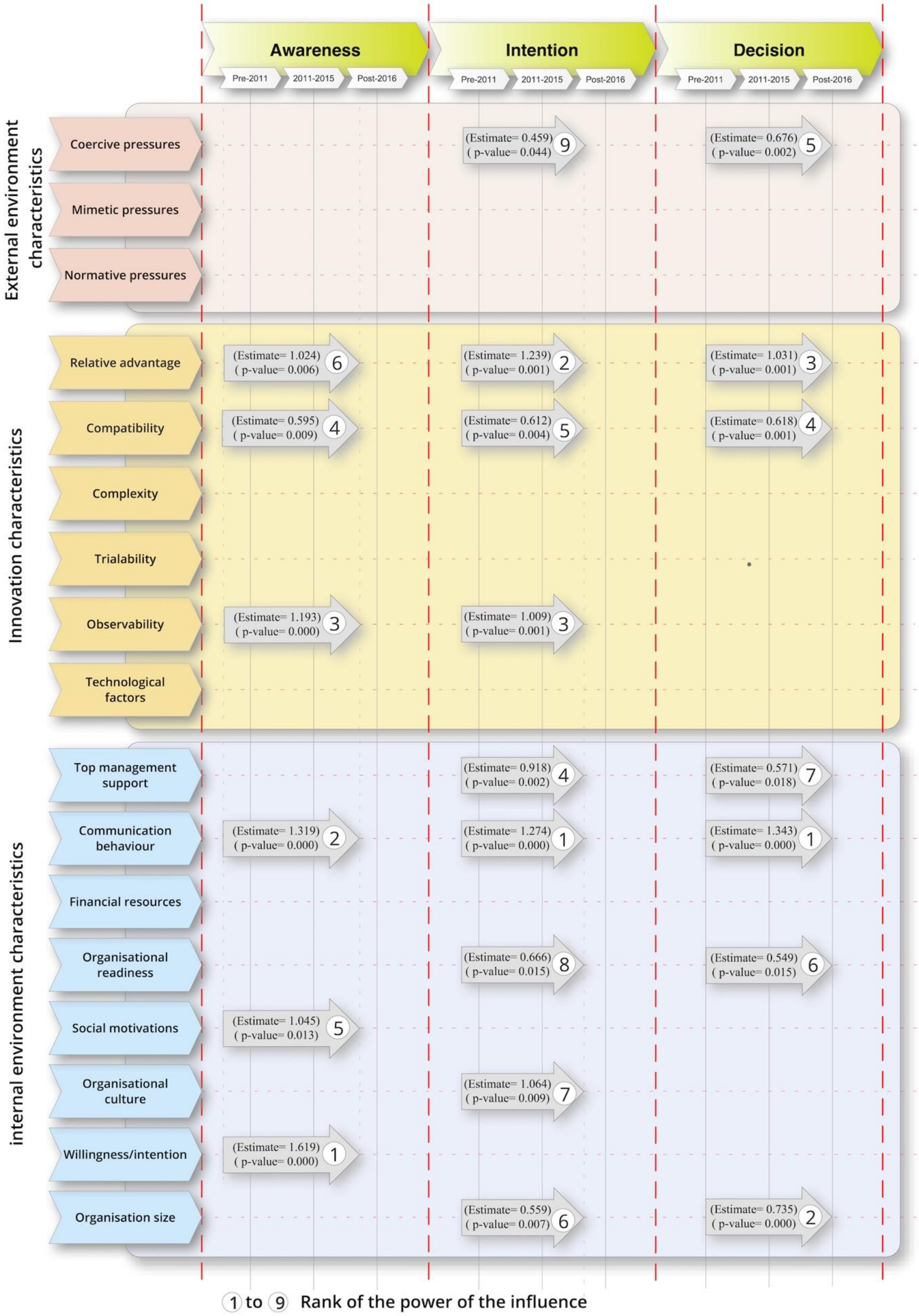


Figure 4: The results of the most influential factors at each stage of the BIM adoption process

8. Discussion

The key knowledge deliverables in this paper (i.e. the taxonomy, and the conceptual model) and the empirical investigation represent a new contribution to knowledge. The UBAT taxonomy is one the first BIM adoption taxonomies that (1) includes an extensive set of adoption drivers and factors, and (2) amalgamates constructs from both the institutional and the diffusion of innovation theories. However, the taxonomy is intended as a mean, not an end in itself. It should form the point of departure for investigating new theoretical explorations and practical questions in the BIM adoption body of knowledge. One such application showing the use of the taxonomy in exploring new research questions was presented in this paper, when the taxonomy was used to develop a conceptual model for investigating the BIM adoption process. The conceptual model was used to explore the influence of the taxonomy's constructs (i.e. drivers and factors) on the stages of BIM adoption by organisations. The model was also used to rank the factors affecting each adoption stage according to their power of influence.

BIM adoption and diffusion studies have proliferated in recent years yet, the majority of these studies have been innovation-centric with the investigated innovation being a finite – not multifaceted – innovation (e.g. a product innovation such as a new learning or communication technology). This study instigates the need for new and tailored BIM adoption studies. This need is supported by the following observations: (1) BIM unlike other finite innovations is a multifaceted innovation (i.e. a product, process and policy) involving multiple stages of implementation targeting different capability stages (i.e. modelling, collaboration, and integration); (2) BIM implementation is also a project network topic affected by interdependences of supply chains (Papadonikolaki et al., 2016); and (3) BIM is one of the fewest innovations within the construction sector that attracted the interest of stakeholders longitudinally across construction sectors (i.e. industry associations, academia and communities of interest) and vertically across countries (i.e. at city, region and nation level). Many countries are investigating and developing national BIM policies to facilitate BIM adoption across their respective markets (Kassem and Succar, 2017). They are increasingly releasing a variety of strategy documents, adoption reports, data exchange standards, and collaboration protocols (Kassem et al., 2015). Existing studies on BIM adoption – as evidenced in the systematic literature presented earlier – have rarely considered the simultaneous potential influence that multiple stakeholders within a market, the supply chain, and a project environment exert on BIM adoption and diffusion. Hence, this study and its further progression are focused on conducting holistic investigations of BIM adoption that are commensurate to the peculiarities of BIM.

The proposed taxonomy and the conceptual model recognise these peculiarities of BIM. They are capable of capturing influences from organisation, project and market environment by merging constructs of institutional theory (i.e. different isomorphic pressure types) with those of innovation diffusion theory (i.e. internal environment characteristics, innovation characteristics). The taxonomy's drivers and factors can be empirically assessed, compared and analysed to understand BIM adoption within organisations and its diffusion across whole markets. The paper has described one such application of the taxonomy that was performed within the UK architectural sector. The influence of the taxonomy's drivers on each of the three adoption stages (i.e. awareness, intention, and decision) was tested and the factors with positive associations with each adoption stage were identified. The factors were also ranked based on their level of influence on each of the adoption stages. The results can help decision makers at organisational level and market wide level to understand the potential impact of certain actions or decisions on the adoption process. For example, an organisation decision maker, knowing that 'communication behaviour' is key to both formulating the intention and decision to adopt BIM, can plan to undertake deliberate actions to improve the organisation's communication behaviour by strengthening intra- and inter- organisational communication channels. Similarly, policy makers can conceive actions to increase channels of communications and interactions between organisations within their respective market knowing the positive influence of this driver on intention and decision to adopt BIM. This result is in accordance with recent policy studies and reports focussed on macro adoption. For example, Succar and Kassem (2015) and the EU BIM Handbook (EU BIM Task Group, 2017) both consider 'communication' as a key area of activity in the process of promoting BIM adoption.

This study also instigates the need to provide both theoretical and empirical evidence of the impact of key external influences (e.g. a country BIM mandate) and their effectiveness while simultaneously considering other types of adoption drivers and factors (e.g. internal environment characteristics, and the innovation characteristics). The knowledge deliverables proposed in this paper can be utilised to measure the combined effect of coercive forces such as a market-wide BIM mandate alongside other adoption factors and comparing their effect on the diffusion of each stage of the BIM adoption process. This analysis could not be included in this paper, but it will delivered in a future paper.

Some of the further research questions with practical significance in the area of BIM adoption that can be addressed using the knowledge deliverables of this paper include:

- Understanding the impact of drivers on BIM adoption within a *single market*: this entails the assessment and comparison of the relative effect of key market-wide drivers such as BIM mandate (e.g. the UK BIM mandate), other isomorphic pressure types, BIM innovation characteristics, and internal environment characteristics on the decision to adopt BIM by organisations.
- Assessing and comparing the impact of drivers on BIM adoption across *multiple markets*: This involves investigating the role of and relationship between BIM adoption drivers/determinants across markets characterised by different diffusion dynamics - i.e. the bottom-up, the middle-out, and the top-down dynamics as identified in Succar and Kassem (2016). The hypothesis underpinning this line of enquiry is that organisational characteristics (e.g. culture, structural complexity, size) and some of their external environment characteristics may alter the influence of certain institutional pressures such as market-wide BIM mandates.
- A specific derivation from the previous question is the comparison of drivers' influence on the stages of BIM adoption across the different time periods underpinning a market-wide BIM mandate. For example, in the UK these time periods would be pre-2011 (i.e. pre-announcement of the UK BIM mandate), 2011-2016 (i.e. trial/implementation period of BIM mandate), and post 2016 (i.e. post mandate).

Domain researchers are instigated to address these research questions. The proposed BIM adoption taxonomy has some limitations. Taxonomies have generally two desirable characteristics: (a) mutual exclusiveness (only one place for any particular thing), and (b) Comprehensiveness of categories/topics (a place for everything). The mutual exclusiveness of factors to their corresponding driver's clusters was verified through the confirmatory factory analysis. The comprehensiveness was practically achieved through the coverage of both BIM and IS literature and the use of the systematic literature review. The limitations affecting the proposed taxonomy's comprehensiveness are those typically associated with the possibility that the SLR omit some relevant studies.

9. Conclusions

Understanding the drivers and the process of BIM adoption is of paramount importance to adopters and policy makers at both organisational and market wide level. The increased connotation and coverage of BIM, compared to other innovations that occurred within the construction sector, warrant a new appraisal of the body of knowledge around innovation adoption. Key gaps and shortcomings identified in the BIM adoption literature include: the dispersion of adoption drivers across several studies due to the specific theoretical lenses adopted by the scholars; the limited attention dedicated to key terms and concepts within the adoption literature (e.g. the interchangeable use of 'adoption' and 'implementation'); and the lack of an extensive BIM adoption taxonomy. This study presented a Unified BIM Adoption Taxonomy (UBAT); developed a conceptual model for guiding the investigation of various research questions pertinent to BIM adoption; and demonstrated its application within the UK Architectural sector by empirically investigating the drivers and factors that influence the stages of the BIM adoption process.

The paper provided an explanation and demarcation of key concepts and terms underpinning the innovation adoption field. It illustrated the details of all stages and steps of the systematic literature review and described the UBAT. The UBAT included three *driver* clusters (i.e., innovation characteristics, external environment characteristics, and internal environment characteristics); 19 *factors* distributed across the three driver clusters; and an extensive set of *determinants.* The UBAT was validated using a confirmatory factor analysis with data obtained from 177 architectural organisations operating in the UK. The results proved that the UBAT's constructs are valid and the instruments used and the data collected are reliable. A successful application of the UBAT and the conceptual model was performed in the UK by retrospectively analysing the first three stages of the BIM adoption process in architectural practices operating within the UK. The application helped identify the factors that influence each of the first three stages of the BIM adoption process and ranked such factors according to their degree of influence.

The suitability of the UBAT and the conceptual model for exploring new research questions within the BIM adoption domain was discussed. It was clear that the UBAT and the conceptual model address the lack of suitable taxonomies and theoretical constructs for investigating an innovation with increased connotations such as BIM. Finally, the paper instigated domain researchers to address a number of BIM adoption research questions that are still unexplored. The taxonomy and the conceptual model, when systematically applied to analyse BIM adoption and diffusion within a specific market, can provide policy and decision makers at both organisational and market level with insights about the potential influence of their diffusion activities.

7. Acknowledgements

This work has been sponsored by the Iraqi Ministry of Higher Education and Scientific Research (MOHESR) jointly with the University of Technology, Baghdad, Iraq. We also gratefully acknowledge the thorough and valuable feedback from Dr. Bilal Succar that helped to shape and improve this manuscript.

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Appendix

Table A1. Systematic Literature Review 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**))

Table A2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Academic journal articles or conference proceedings papers with high methodological standards. • English language material. • Primary studies related to the two research questions. • Studies that have reported the use of theories or developed frameworks and models to investigate BIM/innovation within the construction sector.	• Studies in other-than-English language. • Studies that are irrelevant to the two research questions. • Studies that are un-related to BIM/innovation adoption/diffusion and are not focussed on the construction sectors. • Duplicate materials (i.e. same studies that resulted from the application of different search string or retrieved from different online databases). • Master dissertations, books chapters, conference review, prefaces and opinions.

Table A3. Criteria for quality assessment

QA Item	QA List
QA1. Contribution	Does the 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?

Table A4. An example of a data extraction card

Study number	4
Name of the study	Users-orientated evaluation of building information model in the Chinese construction industry
Author(s)	(Xu et al., 2014)
Year	2014
Publisher (Journal/conference)	Journal: Automation in Construction
Country	China
Study methods considered for data collection	Survey data from the construction industry in China: - Semi-structured interviews: initially conducted with 10 people (executive vice presidents and project managers involved in projects who are familiar with BIM adoption in construction projects). - Questionnaires: postal questionnaires, e-mailed questionnaires, and face-to-face questionnaires.
Study type of analysis	Quantitative statistical analyses
Target level (Macro, Meso, Micro)	Industry-wide adoption in the China construction industry (Macro level)
Name/Type of innovation	BIM adoption
Applied /adopted theories, frameworks, processes, and models attributed to BIM/innovation	- Innovation Diffusion Theory (IDT) and Technology Acceptance Model (TAM). - This study has proposed a research model by integrating TAM and IDT to scrutinise the factors influencing BIM adoption *The model draws on technology acceptance model and innovation diffusion theory and is validated using survey data from the construction industry in China. *Integrated technology acceptance model (TAM) and innovation diffusion theory (IDT), which is used to identify and examine the key factors associated with BIM adoption for potential users and experienced users. The study contributes to the adoption of BIM by overcoming potential obstacles, reducing the risk of failure during implementation and promoting widespread adoption.
Identified drivers and factors influencing BIM/innovation adoption (implementation and diffusion)	The findings of this study have identified/demonstrated that both the Perceived Usefulness (PU) and the Perceived Ease of Use (PEU) are the primary determinants of BIM adoption, with indirect effect of the attitude, technological, and organisational dimensions on the actual BIM use.
Current researcher reflection/review/critique	This study attempted to understand the key factors affecting BIM adoption that would be helpful in (1) promoting further adoption for potential and existing users and (2) improving productivity in the AEC industry. Although this study states that the BIM adoption factors are investigated based on the use of both TAM and IDT, it does rely heavily on the TAM factors rather than factors from both theories. It focuses on BIM adoption from the perspective of predicting users' behavioural intention to accept/reject and to use information systems. The study does consider the external factors that may affect the adoption/diffusion.

Table A5. 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, 2005)	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., 2010)	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%
Average		84%	76%	94%	93%	88%	87%

Table A6. Demographic information of the selected studies, 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/
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, 2005)	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., 2010)	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
Total		72%	79%	75.5%		

Table A7. Theories used to explain BIM and innovation adoption across the 34 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, 2005)	•					
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., 2010)		•		
S33	(Cao et al., 2016)			•	
S34	(Ahuja et al., 2016)			•	•

Table A8. The clusters of BIM adoption drivers across the studies identified

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, 2005)	✔	✕	✓
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., 2010)	✖	✓	✕
S33	(Cao et al., 2016)	✔	✓	✓
S34	(Ahuja et al., 2016)	✔	✓	✓
	Total percentage %	79%	74%	74%

Table A9. 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 risk, and time risk)
		physical risk, financial risk, social risk,
		psychological risk, and time risk
8	**Technological factors**	Interoperability among software applications
		Compatibility among software applications
		Visualisation of design effects
		Supporting characteristics and features
		Information sharing capabilities

Table A10. Internal environment characteristics

No.	Adoption Drivers	Adoption Determinants
1	**Top management support**	Senior management support (internal motivations to actively embrace innovative technologies such as BIM)
		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	**Communication behaviour**	Effectiveness of information flows (communication flows) within organisations
		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 sustain and/or enhance business competitive advantages
		Professional BIM technology training
		Training and support
		Human capability/resources (retention of best people)
		Innovation readiness (e.g. organizational learning, IS infrastructure, and IT readiness)
		Technical competence of staff
		Technological capability of organisation
		Research and development capability of organization
		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 the best people)
		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 than an actual understanding of the real world)
		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 organizational 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/intention**	Level of business interest
		Interest in learning BIM tools and workflows
		Need to change in organisation characteristics for BIM (i.e., types, size, structure, systems, culture, styles, processes)
		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 A11. 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

Table A12. A Sample of the measurement items/ questions

Constructs	**Items**
Coercive pressures	1- Our main clients believe that we should use BIM. 2- Our trading partners put pressure upon us to use BIM. 4- We have adopted BIM to respond to the BIM level 2 mandate by the UK government.
Mimetic pressures	7- Our main competitors who have adopted BIM are perceived favourably by clients.
Relative advantage	17- Adopting BIM is perceived to improve the productivity of our organisation. 21- Adopting BIM is perceived to improve task performance.
Compatibility	23- Adopting BIM is perceived to be compatible with existing processes in our organisation.
Trialability	30- We adopted BIM after a trial period.
Technological factors	36- The availability and affordability of BIM technology were key in the decision to adopt BIM.
Top management support	38- Our top management has the willingness to support change
Communication behaviour	42- Our organisation initiated a network of connections to know more about BIM when we first time had heard about it.
Financial resources	48- Our organisation perceived BIM as an affordable innovation.
Organisational readiness	52- Our organisation has provided a professional BIM technology training.
Social motivations	61- It was necessary that both the individuals and groups in our organisation share the motivation for BIM adoption.
Organisational culture	70- BIM adoption requires organisational restructuring.

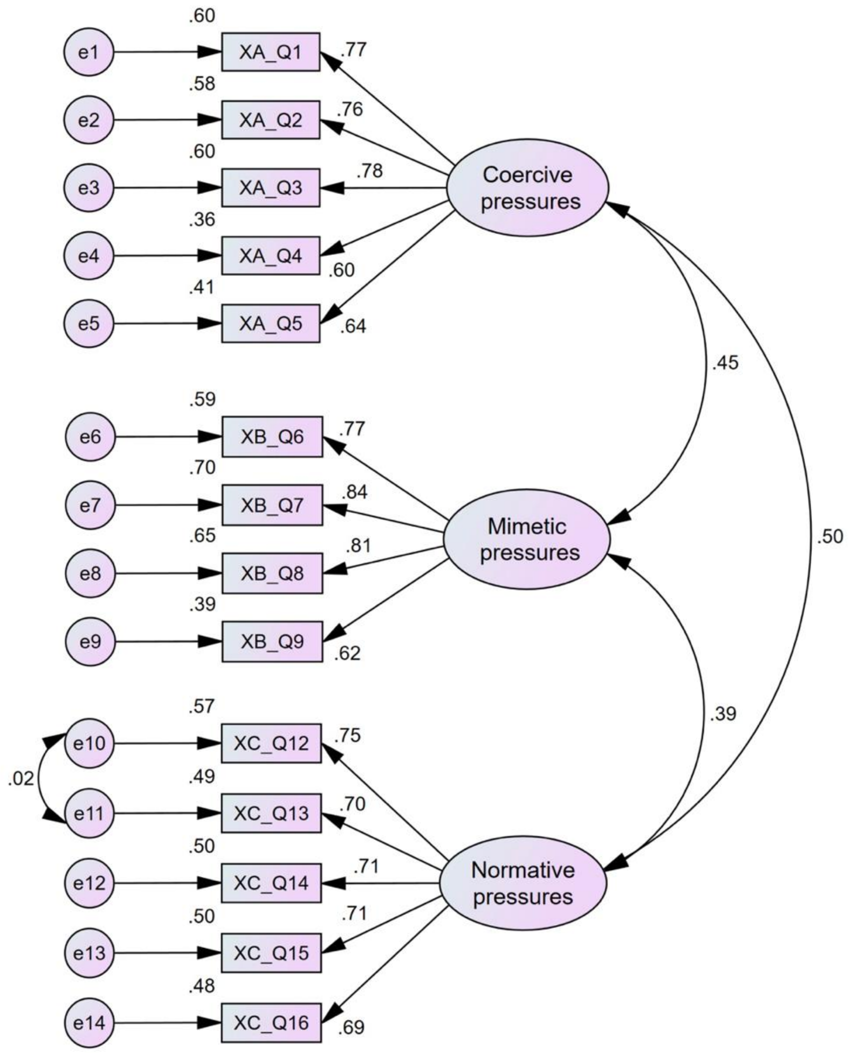

Figure A1: CFA measurement model of the *External Environment Characteristics* construct

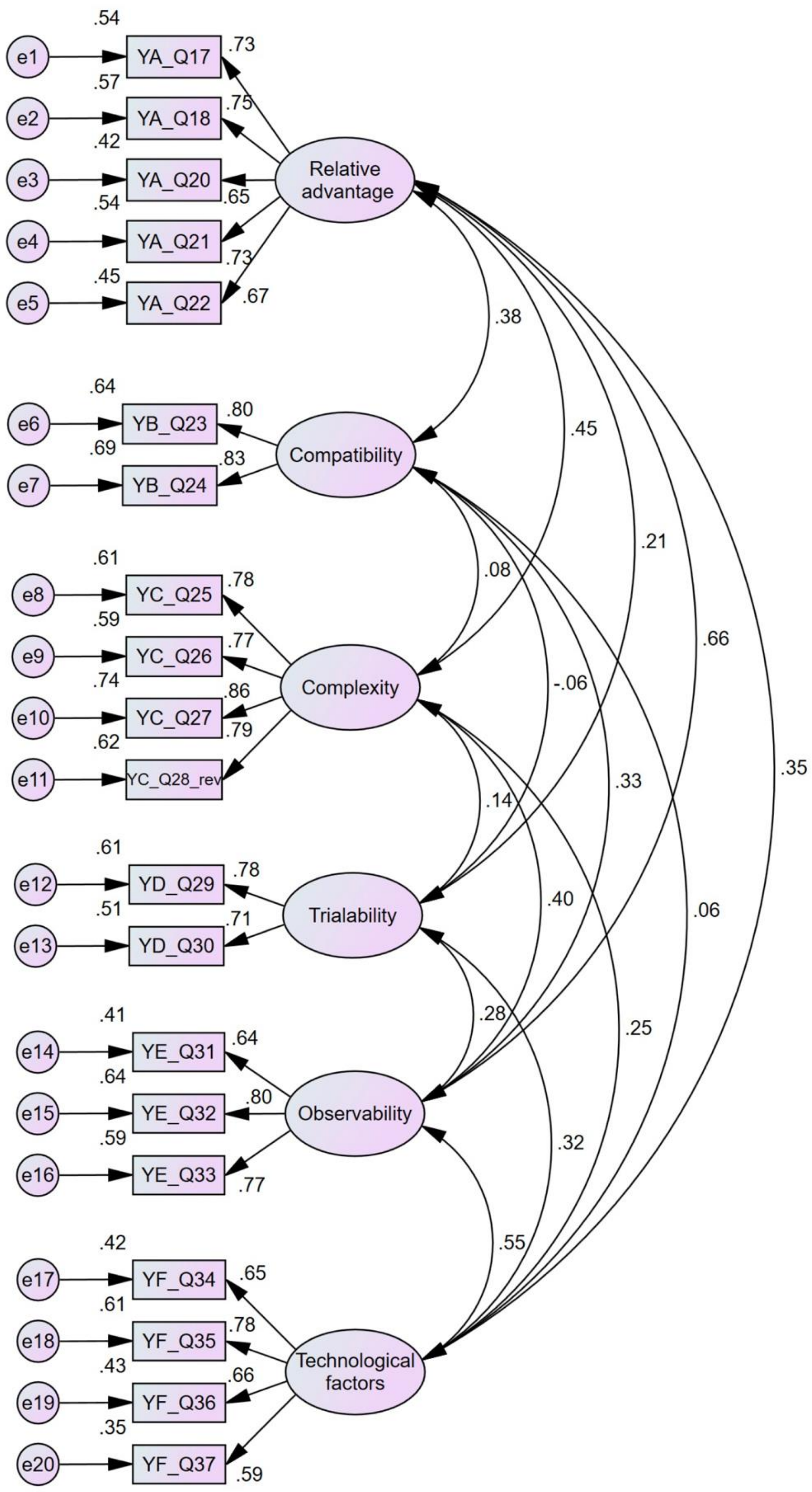

Figure A2: CFA measurement model of the *Innovation Characteristics* construct

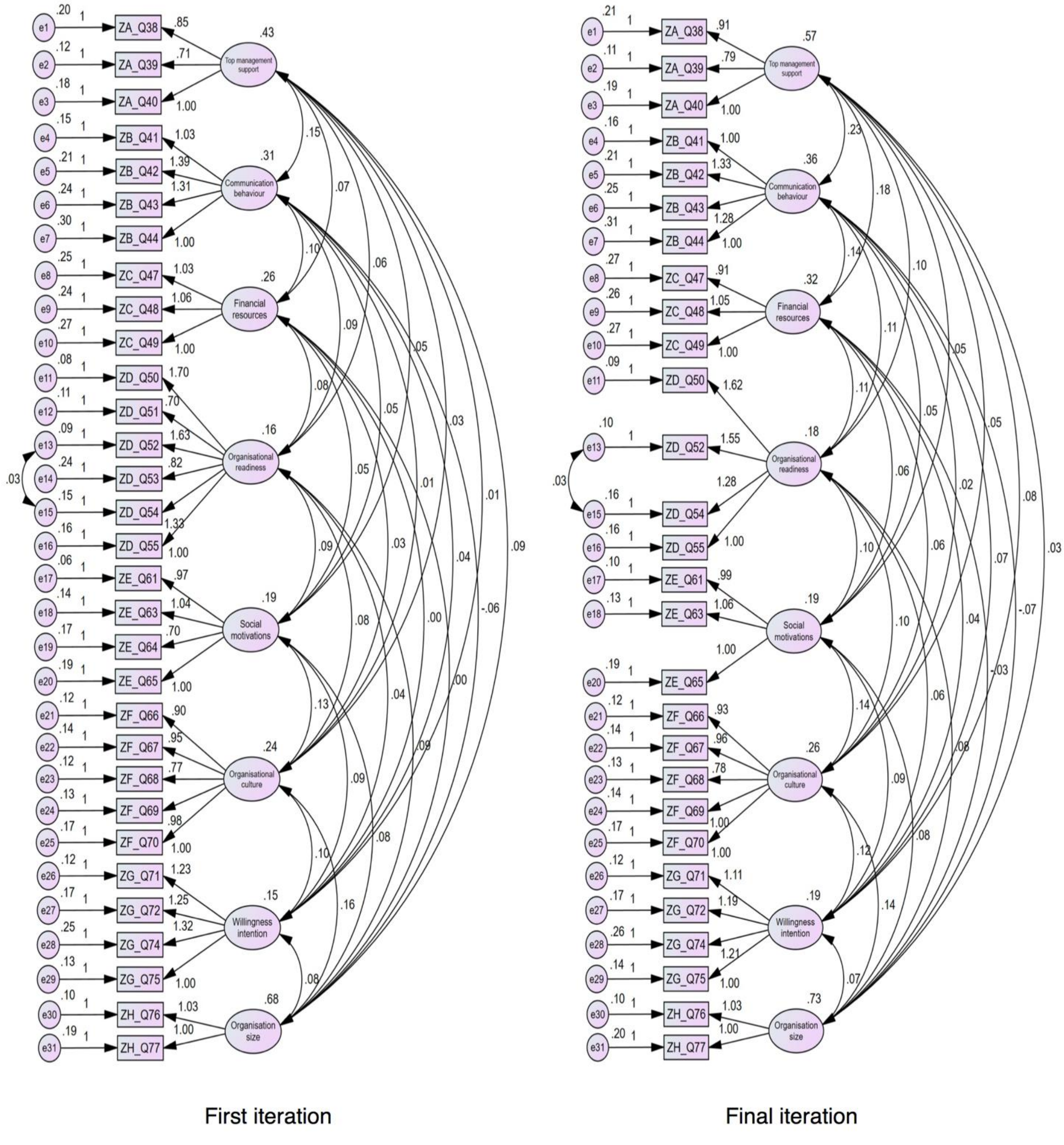

Figure A3: CFA measurement models of the *internal environment construct*