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Enhanced model of the innovation-decision process, for modular-technological-process innovations in construction.

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Enhanced model of the innovation-decision process, for modular-technological-process innovations in construction.

Purpose: An enhanced model of the innovation-decision process, specifically for construction is established. As context, innovation diffusion theory (IDT) is concerned with explaining how some innovations successfully stick whilst others fail to propagate. Because theoretical models provide abstracted representations of systems/phenomena, established IDT models can help decision-making units (DMUs) with innovation-related sense-marking and problem solving. However, these occasionally fail, or require enhancement to represent phenomena more successfully. This is apparent whenever middle-range theory seems ill-fitted to the complexity of construction.

Design/methodology/approach: Qualitative research via 13 semi-structured interviews occurred, with participants recruited via convenience and purposive sampling strategies. The work forms part of a broader mixed-method study informed by a research philosophy of pragmatism, investigating the applicability of classic IDT to the adoption of 4D Building Information Modelling (4D BIM) by the UK construction sector.

Findings: This diffusion study resulted in the adaptation of an existing innovation-decision process model, ensuring a better contextual fit. Classified more specifically as a modular-technological-process innovation, 4D BIM with its potential to provide construction planning improvements is used as a vehicle to show why, for construction, an existing model required theoretical extensions involving additional stages, decision-action points, and outcomes.

Originality: An enhanced model of the innovation-decision process, specifically for construction, is established. This construction-centric contribution to innovation diffusion theory, will be of interest to construction scholars, and to practitioners.

Implications: This model can assist construction industry actors with future adoption/rejection decisions around modular-technological-process innovations. It also aids understanding of scholars and researchers, through its various enhancements, and

by reinforcing the importance of existing diffusion concepts of compatibility and trialability, for these innovation types.

Keywords: 4D BIM; construction scheduling; diffusion; innovation; planning & management.

Introduction

In attempting to improve aspects of construction project-delivery, efforts sometime focus on how to exploit relevant innovations, harnessing their benefits as possible solutions to key challenges. An innovation is some 'thing', unfamiliar to an entity, that can facilitate product, process, or systemic improvements. In this work, the concern of time predictability in the delivery of UK construction projects is discussed, before 4D BIM is briefly introduced and positioned as an innovation with potential to provide improvements to construction planning and possibly to project time performance. However, there are concerns around the prospective industry absorption of 4D BIM because innovations do not always have their promised transformational effect, and they may 'take off' more slowly than expected, or not at all. Classic Innovation Diffusion Theory (IDT) helps explain how some innovations successfully stick, whereas others fail to do so. The phenomena of innovation diffusion occurs across society, but as the construction sector in particular, is perceived to suffer from a low 'innovation rate', this topic remains worthy of investigation within the context of construction.

The twin aims of this work are: to investigate the applicability of classic IDT to the adoption of 4D BIM by the UK construction industry, and; to use a study of 4D BIM diffusion to build upon classic IDT, developing a more relevant model for the construction sector for similar innovations. Following discussions around time predictability, innovation, classic innovation diffusion theory (IDT), and a demand for further research into construction innovation diffusion, 4D BIM is then defined as a modular-technological-process innovation. Then, synthesised results from a doctoral research programme focusing on the diffusion of 4D BIM are presented. These reveal how for the construction sector, an existing albeit too-general innovation-decision process model required theoretical extension to better serve industry actors in their diffusion considerations about modular-technological-process innovations.

Time predictability problem in construction project delivery

Construction is perceived as underperforming, particularly regarding project delivery (Love *et al.* 2011). Industry reviews regularly identify long-term concerns and there have been several calls to reform apparent poor performance. Recurring criticisms involve issues such as fragmentation, inefficiency and waste (Egan 1998, Wolstenholme 2009, Farmer 2016, McKinsey Global Institute 2017). Furthermore, the varying ability of construction organisations to respond to, and capitalise on innovations have been highlighted (Larsen and Ballal 2005, Hosseini *et al.* 2015, Murphy *et al.* 2015). Reviewing long term inefficiency concerns, Egan (1998) highlights how innovative technologies and processes, including 3D object orientated modelling may provide solutions, stressing also the need for industry performance measurement. Following such recommendations, use of UK industry-standard Key Performance Indicators (KPI's) commenced in 1999. Particularly relevant here is the KPI 'time predictability', in which, Egan (1998) originally advised targeting a 10% annual reduction. Such focus on improving the time predictability of UK construction projects remains. The UK construction 'Vision for 2025' strategy document (HM Government 2013) calls for 50% faster project delivery by 2025, with reductions in overall time, from inception to completion, for new build and refurbished assets, benchmarked against 2013 UK industry performance[1]. Despite such aspiration, analysis of annual KPI data reveals that UK construction project time predictability has not demonstrated sustained improvements in any measure of time predictability, and more than half of UK construction projects continue to exceed their agreed time schedules (entire project durations). Table 1 shows annual KPI data reported for measures of construction time predictability in the ten-year period 2009 to 2018, also providing the 10-year average.

Table 1: Construction time predictability for years 2009–2018, percentage of projects and phases delivered on time or better. Adapted from Glenigan (2018)

INSERT TABLE 1 HERE

4D BIM - potential solution

Crotty (2012) asserts how poor-quality project information results in two key issues for the UK construction industry, poor (time and cost) predictability and profitability. A UK government drive for all major construction projects to be working at "*fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016*" was an important step toward improving the quality of project information across the industry (HM Government 2017). This was based on the belief that BIM is an innovation to improve design output quality, and

[1] 2013 benchmark where only 45% of UK construction projects were delivered on, or before their original planned project end dates.

overall design and construction processes including the time performance of construction projects (Li *et al.* 2009, Sacks *et al.* 2018). BIM enables use of 4D methods, where the dimension of time is linked to the 3D model (x + y + z + t) allowing visualisation and aiding communication of the spatiotemporal relationships of construction activities (Liston *et al.* 2001, Buchmann-Slorup and Andersson 2010). Literature considers use of 4D methods as an aid to planning, and a useful addition to project scheduling (Koo and Fischer 2000). 4D BIM can also be used to analyse construction schedules to assess their implementation (Mahalingam *et al.* 2010, Trebbe *et al.* 2015) thus helping reduce errors through plan interrogation and validation.

Given the emphasis on the need for quicker delivery of construction projects, the continuing record of poor time predictability, and the broad endorsements that BIM implementation can improve project delivery, there is presently much focus on how 4D BIM can improve the planning of construction projects. However, whilst it appears that 4D BIM is a process-based innovation that can help improve construction project time predictability, because concerns have previously been identified with innovation adoption in construction (Winch 1998, Larsen and Ballal 2005) more research into industry innovation diffusion efforts are encouraged (Larsen and Ballal 2005, Harty 2008).

Innovation

An innovation is not the generation of an idea, but instead involves exploitation, implementation and management of such ideas, or inventions, creating value through their practical and commercial benefits (Kastelle and Steen 2011). Innovations offer non-trivial improvements in products, processes or systems and are unfamiliar to the company/institution (aka decision-making units) developing/making use of them (Hosseini *et al.* 2015). Innovations should be considered in terms of their disruption to the systems they are introduced into, with systems being considered as either simple, complicated or complex. In construction, both projects (Baccarini 1996, Williams 1999) and the industry itself (Bertelsen 2003, Harty 2005), have been described as complex systems, meaning they have large numbers of parts, with uncontrollable dynamics, making all possible outcomes difficult to predict (Loosemore 2014). Whilst construction innovations could seemingly help bring about time and cost reductions, and safety and quality improvements, thus improving competitive advantage and market share, when compared against other sectors, very frequent innovation in construction does not appear to occur. One explanation offered by Dubois and Gadde (2002) is that, because of the complexity of construction, its system "*favours productivity in projects, while innovation suffers*" (p629). Though a low industry innovation rate is refuted by Winch (2003), such framing remains useful when discussing innovation diffusion in construction.

Construction innovation – types and frequency

Slaughter (1998, 2000) advising also of the impacts that innovations can have on systems, conceptualises five innovation-types in construction. These are: 'incremental innovations' offering minor improvements over existing practices with minimal impacts on a system; 'architectural innovations' whose consequences may mean reshaping many system constituents; 'modular innovations' which may produce significant improvements but may not require alterations of other system-level components; 'system innovation' being the introduction and interaction of multiple complementary innovations, and finally; 'radical innovations' completely new approaches, meaning a redesign of the entire system being necessary. Slaughter advises that the implementation of each type needs varying levels of managerial input/commitment. On this, researchers (Koskela and Vrijhoef 2001, Reichstein *et al.* 2005) argue that the most frequent innovations in construction are incremental or modular types, and are usually product- rather than process- based, generated by suppliers, because of difficulties in implementing more radical innovations requiring larger scale systematic changes. Similar to Winch (2003), others (Taylor and Levitt 2004, Taylor *et al.* 2004) argue that the rate of incremental product-based innovations in construction is no worse than in comparable sectors, yet because of the structural complexity of project-based industries, systemic process-based innovations that need to cross organisational boundaries diffuse slower. And whilst Koskela and Vrijhoef (2001) call for the introduction of more radical process-based innovations, Winch (1998) reflects that "*innovation efforts in the industry are disproportionately orientated towards product-enhancement rather than process-improvement*".

BIM and 4D BIM as innovations

Despite this, the introduction of Building Information Modelling (BIM) within construction, has been a very visible technological innovation and the Organisation for

Economic Cooperation and Development note how technological innovations can be categorised either as product or process innovations. Poirier *et al.* (2015), also agree that technological innovations include both these types. Succar (2009), identifies the impact of BIM thus, "*Building Information Modelling (BIM) is an emerging technological and procedural shift within the Architecture, Engineering, Construction and Operations (AECO) industry*". BIM has variously been classified both as an innovation (Davies and Harty 2013) and as disruptive technology (Succar *et al.* 2012). Poirier *et al.* (2015) note "*BIM is seen by many as being a disruptive innovation, which is bringing about the reconfiguration of practices in the AEC industry*". Gledson (2016) concurs, identifying that "*the most prominent radical, transformative and disruptive innovation to hit construction industry is the use of Building Information Modelling*".

Building upon these various definitions of BIM as a technological innovation, a more detailed classification of 4D BIM being a modular-technological-process innovation is proposed. This is because:

- As above, BIM is widely considered to be a 'technological innovation' (Succar 2009, Dainty *et al.* 2017, Li *et al.* 2017).
- Though (3D) BIM is considered as "*an integration of both product and process innovation*" (Georgiadou 2019), 4D BIM which enables a new way of planning, is more readily 'process innovation' because it facilitates improvements in the process of production. Also, the act of 4D planning in making use of BIM technology models only the construction process itself, rather than the building product (Elghaish and Abrishami 2020).
- 4D BIM also meets Slaughter's (1998; 2000) conceptualisation of a 'modular innovation', as it allows better modelling of the planned construction process, which can result in substantial production improvements. The process involves using 4D technology either as a substitute for more conventional planning and scheduling tools, or as an 'add-on' to existing planning tools, meaning it does not require the alteration of other 'system-level' components.

For DMUs unfamiliar with BIM/4D BIM, these are innovations. They can provide process related benefits; generate value to organisational strategic outcomes; and enable competitive advantages. An in-depth discussion of 'the how' of 4D BIM is outside the scope of this work, which is more with concerned the innovation-decision process in construction, and as such now turns to matters of innovation diffusion.

Innovation Diffusion

Diffusion is concerned with the spread of innovations. Various researchers identify the need for greater innovation diffusion research both on the construction industry (Larsen and Ballal 2005) and its projects (Harty 2008). Gambatese and Hallowell (2011b) identify a need for research into the "*identification and dissemination of new technologies, systems and processes that have the potential to become innovations within the construction industry*". These researchers also identify the importance of evaluating the impacts and benefits of innovations, as well as undertaking research into their use in construction. In responding to such calls, Rogers (2003) innovation diffusion theory is used, as a starting point to investigate further.

Rogers (2003) Diffusion of Innovation Theory

Everett Rogers (2003) popularised the 'Diffusion of Innovations' theory of how, why, and at what rate, new ideas and technology spread through cultures. Since its first edition was published in 1962 Rodgers has been cited over 128,000 times, and a brief explanation of several key points and concepts is necessary. Various management and construction scholars who have built upon Rogers work are discussed within a subsequent section. Rogers defines diffusion as the "*process in which an innovation is communicated through certain channels over time among members of the social system*" (2003, p5). Innovation diffusion communication is primarily concerned with new ideas and is identified as being between multiple individuals, as a two-way process. This definition contains all four elements: the 'innovation'; its means of information transfer or dissemination through 'communication channels' (either personal, or non-personal such as mass media); across 'time'; amongst members of a structured set of interrelated units i.e. 'the social system'.

Throughout, several concepts (identified here using italics) and elements of IDT are introduced by Rogers, including:

- How social system members determine the rate of innovation adoption because of the *Perceived Attributes* (characteristics) of the innovation. Specifically, these involve its *Relative Advantage; Compatibility; Complexity; Trialability*; and *Observability*.

- Communication channel effectiveness: Whilst non-personal channels can be effective in mass communication transfer of high value information, in diffusion, individuals place greater emphasis on the subjective judgement of near-peers rather than in experts objective judgements.
- Classifications within a population, as dependent upon the timing of adoption: *Innovators* (2.5%); *Early Adopters* (13.5%) and the *Early Majority* (34%) are the first 50% of a population reaching a point of critical mass. Following these are the *Late Majority* (34%) and *Laggards* (16%).
- The norms and rules within a social system as constructed by its individuals and key actors, including *Innovators, Opinion Leaders*, and *Change Agents*.
- Classification of adopt-reject decisions, either as discrete-, or connected-decisions*: Optional Innovation-Decisions*, made by individuals, *Collective Innovation-Decisions* made by consensus, and for *Authority Innovation-Decisions*, adoption commitment is imposed by a few controllers or influencers. *Contingent Innovation-Decisions* are when more than one (i.e. connected) individual innovation-decisions are made.
- Consequences - intended and unintended, positive or negative, of implemented innovations.
- The innovation-decision process (IDP)[2] of innovation *Knowledge; Persuasion; Decision; Implementation* and *Confirmation*, that ultimately leads to innovation adoption or rejection. It is the enhancement of this aspect of IDT that is the focus of this work, with a new contextual model of IDP presented in the results section.

What models are

Models help navigate the complexity of the world by providing a simplified, or idealized representation of some phenomenon, or system. They are abstractions,

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[2]Emmitt (1997) previously considered the applicability of IDT to the UK construction industry also focusing on the IDP, looking at the decisions made in the adoption or rejection of innovative building products. Emmitt's work proposed the notion of 'postponed adoption' which is also used here, where an innovation is not immediately adopted or rejected but knowledge of it is retained for potential future application.

containing assumptions or observations about the relevant, decomposed, elements of a system or real-world situation, useful for purposes such as generating visualisations or simulations, drawing inferences, making predictions, or problem-solving. "*The purpose of the model is not to describe reality but to reduce it to a more manageable form, losing many of the minutiae of reality, but, hopefully, retaining the general form in a way which is more easily understood*" (Raftery 1998). People use them in everyday situations, though they tend not to be thought of as models, with examples including maps, paintings, photographs, diagrams, toys, video games and other computer-generated simulations. Models are used across most academic disciplines. Within the social sciences, conceptual models[3], are commonly used for sense-making purposes, to facilitate better understanding, and convey meaning. Raftery (1998, pp.299–300), also suggests models are "*useful only as long as they appear to fit their situation, to describe or analyse a problem adequately. They are useful until they are disproved*". Where some models fail at points and require complete revision, others merely require refinement or enhancement, so they continue to exhibit likeness to the phenomena being represented.

Building upon Diffusion Research

The enhancement of Rogers IDP model is presented in the results section (Figure 1). Though it has largely been accepted as generalizable across organisational-, marketing-, product-, or process-based innovation-decisions (Windahl *et al.* 2008), it has also faced specific criticisms within the construction management research community. Several researchers (Shibeika and Harty 2015, Lindgren and Emmitt 2017) point out that because of the peculiarities of the sector - it being project-based, structurally complex, risk averse, suffering from short-termism, and bounded by uncertainty (Barrett and Sexton, 2006; Loosemore and Richard, 2015) – for it to be applicable within construction, Rogers' model requires theoretical extension. Larsen (2005) argues it is "*a practical yet almost over generic theory with inadequate consideration of context*".

Therefore, several researchers have since built on aspects of Rogers work. Greater focus has been placed on the nature of innovation itself (Dodgson and Gann 2010), to other

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[3] Raftery (1998) lists a fuller range of model types, in an excellent account of what models are.

IDT components including communication channels, the nature of social systems and the innovation diffusion process (Bass 1969, 2004, Moore 2014). The impact of Rogers' adopter roles and their approximate percentages within a population has also been revisited within general-, and construction-, management literature (Goldenberg and Oreg 2007, Edwards 2014). The most notable additions to diffusion research include the work of Frank Bass who developed a mathematic model helping predict the diffusion of an innovation, and Geoffrey Moore (2014) who contended that, for adoption of disruptive innovations in particular, a 'chasm' must be crossed between the earliest adopters of an innovation and the early majority because of their differing expectations.

A need for further research into construction innovation diffusion

As noted, interest in innovation within the construction environment and project-based organisations has grown since the late 1990's. Miozzo and Dewick (2004) consider there is a scarcity of analyses of innovation within construction. Reichstein *et al.* (2005) advise of too few large-scale surveys of construction innovation. Kale and Arditi (2010) note that from 2004 a surge in construction studies exploring innovation diffusions had occurred, yet few of these used recognised and valid theoretical diffusion models. Prior CM diffusion research includes: investigations into general IDT theory within construction (Larsen and Ballal, 2005); diffusions of managerial innovations, such as: lean construction (Green and May 2005), and; administrative innovations, such as quality management processes (Kale and Arditi 2006). There is much focus on technological innovations including: construction technology (Slaughter 2000) general ICT (Peansupap and Walker 2005, Panuwatwanich *et al.* 2009); CAD (Kale and Arditi 2005); 3D CAD (Tizani 2007); and BIM (Fox and Hietanen 2007, Brewer and Gajendran 2012). Alternative diffusion research efforts have made use of systems dynamics (Park *et al.* 2004), and social network analysis (Larsen 2011). Whilst use of classic IDT remains appropriate for undertaking investigations on innovation adoption in the UK Construction sector, efforts to interrogate it also seem welcome.

Methodology

A mixed-method study informed by a pragmatist philosophy occurred, resulting in a doctoral-programme knowledge contribution. Pragmatism allows for use of mixed methods research (often referred to as the third research paradigm) to address research aims/questions (Johnson and Onwuegbuzie 2004, Morgan 2007). As before, the aims were to investigate the applicability of classic IDT to the adoption of 4D BIM by the UK construction industry, and; to use a study of 4D BIM diffusion to build upon classic IDT, developing a more relevant model for the construction sector for similar innovations.

The population of interest was those UK construction sector organisations looking to innovate by incorporating BIM/4D BIM within project delivery practices. Relevant individuals, primarily construction planners and project managers representing such organisations therefore became the focus of data collection strategies on a multi-stage non-probability project[4]. Participants were therefore accessed through convenience and purposive sampling strategies. Whilst there are difficulties in quantifying such a population, of the 1,650,000 professionals that Myers (2013) estimates as being directly involved in the delivery of UK construction projects, and following discussions with the CIOB and APM professional bodies, these practitioners can be reasonably assumed to be in the tens of thousands. Regardless, 246 participants were involved overall, with multiple data collection and analysis strategies used across the programme. It contained initial exploratory work, using case study and questionnaire survey research, and latter work employing a second questionnaire survey and this final round of semi-structured interviews with 13 suitable participants drawn from across the programme (qual > quan > QUAN + QUAL). Ethical approval was given by the institutional ethics committee, and deductive research was applied throughout.

Though mixed-methods were used throughout the programme, data were gathered and analysed separately for each distinct phase (e.g. qualitative data was only analysed using qualitative methods and similarly quantitative data was only analysed via quantitative methods), before now, results were not previously synthesized for presentation. However, these mixed methods are now useful for providing what Johnson and Onwuegbuzie (2004) refer to as the 'complementarity' of results (i.e. using results from one method to enhance the results from another method used) within the programme. Previously, findings from an exploratory case study investigating the

[4] Noting also that from the circa 273,775 related UK 'construction' businesses, or 65,443 registered industry contractors (ONS 2016) there's no way of truly determining how many firms were actively looking to innovate in their approach to project delivery.

consequences of a decision by a large contracting organisation to adopt the use of BIM across all of their future projects were published in Gledson (2016). Then results from two separate questionnaire surveys about the UK construction industry were published, the first investigated the extent and use of 4D BIM in construction planning (Gledson and Greenwood 2016), and the second used classic IDT methods to measure the adoption rate of 4D BIM[5] (Gledson and Greenwood 2017). Now presenting an enhanced model of the innovation-decision process for modular-technological-process innovations in construction, qualitative findings from the final round of semi-structured interviews are now primarily drawn upon, albeit these findings are reinforced in some places by prior results for purposes of such complementarity.

Results, analysis, discussion

Analysis of results reveals that to better reflect the diffusion of modular-technological-process innovations within the construction sector, several enhancements to Rogers (2003) model are required. Therefore, the IDP for such innovation types follows a similar, albeit amended process explained herein.

A new model of the innovation-decision process

This new model for modular-technological-process innovations, diffusion consists of 6 more involved stages. Each stage and the aspects within them, are now described. Enhancements to the existing model are verified and supported via the findings from the research programme, meaning that 4D BIM and innovation-decisions around its diffusion are used as the vehicle to evidence these. Amendments to Rogers IDP model are shown in Figure 1, with most enhancements shown as black textboxes with white text.

INSERT FIGURE 1 HERE

Figure 1: Enhanced model of the innovation-decision process for modular-technological-process innovations in construction.

[5] Done using several of the aforementioned IDT elements, and identifying their necessary and sufficient conditions, to determine a rate of 4D BIM adoption amongst construction actors surveyed.

Exposure

Rogers (2003) initial ‘knowledge’ stage is replaced by two closely related, but distinct stages. At the outset of the IDP, decision-making units (DMUs) are at the threshold of the (I) *exposure* stage, passive in terms of information-seeking behaviours until first exposed to an innovation through communication channels. Thus, the actions of opinion leaders as promoters or gatekeepers of innovation remain important, and at this stage one-way ‘initial innovation messages’ received are either discarded or investigated. Thinking about DMUs as being passive to begin with, challenges an earlier argument that DMUs are instead more active information seekers at this earliest stage of the innovation decision process (Larsen, 2011, p990). Yet interviews here reveal that DMUs first became aware of modular-technological-process innovations only through chance, thereby exhibiting passive, rather than active information-seeking behaviours. Responses suggest that at this threshold, ‘exposure’ occurs because of innovation messages by opinion leaders or change agents, or communications transmitted at work (company briefings) or from educational institutions. Data reveals how exposure also occurs through professional event participation, or via personal networks. Notably, it occurs increasingly, through media consumption. It is worth commenting that the influence of modern media on innovation diffusion within construction, and across society, has expanded enormously since Rogers’ first (1962) and last (2003) editions of ‘The Diffusion of Innovations’. Hence, DMUs can now be inundated with these ‘initial innovation messages’, but not just through traditional print media, or radio or television broadcasts. Exposure now also occurs through web browsing, or via ‘webinars’, or by participating in online groups.

For 4D BIM, Participant 100 described their initial exposure to it as it: “*Being on YouTube clips. Also, it was starting to get talked about in magazines*”. Participant 246 discusses how, in terms of innovation (in contrast to getting information from their organisation), online media is ‘up-to-date’, ‘cutting edge’, and “*telling you what’s happening now*” (Participant 246).

Exploration

> “*My first knowledge of 4D BIM came through university, and then through my studies I learnt what it was. It interested me so I pursued it on my own … a lot of*

my first knowledge was just through studies and self-interest, rather than being introduced to it by the company" (Participant 15).

Like Participant 15, it is only after 'exposure' that DMUs continue through the IDP. They enter the (II) *exploration* stage, and depending upon their characteristics and perceived needs, they may begin to demonstrate more active information-seeking behaviours. The DMU starting the process of formulating a decision, again may choose to discard innovation information messages, or may progress to the next stage. Here, this model further differs from Rogers's by recognising that after the initial exposure stage, communication channels then involve 2-way acts of communication with *active information-seeking* performed by DMUs to supplement received messages. At each subsequent stage, DMUs continue to seek 'information messages', progressing through the decision-making process but may still exit the IDP at any stage if experiencing discordance. Hence, as shown in this model, communication behaviours of DMUs become particularly important from here onwards.

Semi-structured interviews reveal that regarding 'exploration', participants expressed preferences for using internal communication channels because of issues of 'integrity', 'trust', and the importance of two-way communication. Participant 189 called it 'human nature' and argued that: "*... you're more receptive and rather ask 'daft' questions* [being] *prepared to embarrass yourself more easily with people you've known for years ... Perhaps you might not in an external environment*". Participant 210 emphasised that, when explored using internal communication networks, innovation information could be discussed and challenged, rather than merely being 'obtained'.

From this point on, remaining stages in this IDP model remain as per Rogers' original model, albeit with other enhancements being an additional 'environmental factor' (of *external agency communications*), and additional 'decision-action points' and 'outcomes'. Again, these are typically shown as black text boxes with white text on Figure 1 and are discussed throughout.

Persuasion

(III) *Persuasion* occurs when an impression/attitude is created about the innovation. With modular-technological-process innovations such as 4D BIM this research programme confirms that although Rogers perceived innovation characteristics of 'relative advantage', 'compatibility', 'complexity', 'trialability' and 'observability' still play a role at the persuasion stage, 'trialability' (the opportunity to experiment with, and use the innovation without commitment), and 'compatibility' (between the innovation, and existing infrastructure), and for this particular innovation, certain 'relative advantages' (i.e. in plan communication) are more significant than 'complexity' and 'observability'[6].

Analysis also reveals how, aside from perceived innovation characteristics, persuasion also occurs. At this stage, the effects of direct communication from relevant external agents upon the innovation-decision environment are most strongly felt. These may also influence or persuade any adoption/rejection decision made. Hence, *external agency communications* also provided further model enhancement.

Key innovation-information messages from Government and other marketplace actors were relevant for 4D BIM diffusion. Examples:

- Within the UK Construction, the UK Government provides the best example of an 'external agent' by combining policy, regulation and championing behaviours (their importance to innovation is recognized throughout the literature, e.g. Gann and Salter 2000, Aouad *et al.* 2010, Caerteling *et al.* 2013, Na Lim 2014). For 4D BIM, Governments role within the 'persuasion stage' of the IDP was summarized by Participant 210: "*if you look at the macro level, Government Strategy provided the focus, and the aim for people, of where to get to. Its gamification of the project environment, gamification of the industry*".
- Another example of how external agency communication affect persuasion comes from marketplace interactions. Data revealed concerns by DMUs around if, and how, competitors were adopting innovation, thus influencing attitudes, and initiating 'imitative' behaviours. Fears usually centred on how their own company is performing, against competitors (i.e. if they are falling behind or

[6] Gledson and Greenwood (2017) performed inferential tests for 'trialability' and 'compatibility', yielding significant, Fisher's Exact Test Statistics of .005, and .026 respectively.

being expected to be using it)[7]. For 4D BIM, this was evidenced by Participant 189, reflecting upon an experience attending 'post –tender interviews':

> *"... we took our 3D model along, to show site logistics and sequence, to demonstrate that we understood the works, the problems, and tried to find solutions. We thought it would go down very well, but the feedback was that the other three tenderers had something similar. So now, if you went, and you didn't have something like that, you would look inferior, even if your ideas were good. It's almost as if it's now expected of you".*

Decision

(IV) *Decision* stage occurs when a DMU adopts or rejects the innovation. In Rogers model, only four outcomes were listed, that: Initial decision to adopt is followed by 'continuous adoption' or later 'discontinuance' of the innovation, or; initial decision to reject can be followed by 'continuous rejection' or by 'later adoption'. This enhanced model however reveals that in the construction sector it is more likely that for *modular-technological-process innovations* one of five more nuanced 'outcome types' occurs. The most typical outcomes are *gradual-adoption*, *postponed-adoption*, or *passive-rejection*, and rarer outcomes include *immediate-adoption* or *outright-rejection*. Owing to the project-based nature of construction, any adoption decision made is usually a 'postponed-adoption', or a 'gradual-adoption' decision. This is because 'if and when' adoption decisions are largely related to the timing and requirements of individual projects. Complementary results from Gledson and Greenwood (2017) reinforce this, evidencing that for 4D BIM, the usual time lag reported between first awareness and adoption was between 28.5–36.0 months. This supports the model enhancements that innovation adoption in construction is more typically 'gradual' or 'postponed' but rarely 'immediate'[8].

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[7] Whilst such concerns may apply to 2nd/late 'movers', other organisations considered as innovators/early adopters (i.e. 'first movers'), were found to have their own concerns around trying to actively restricting innovation communications and marketplace interactions. These were organisations that had positioned themselves to offer 'differentiation' to clients through a unique selling proposition (USP) and providing business benefits derived from innovate behaviours appear to act differently. For this reason, the data suggests that such organisations become much more internally focused to retain that competitive advantage.

[8] Gledson and Greenwood (2017) show that whilst 63.0% of respondents confirmed 4D BIM use/awareness of use from someone in their organisation, only 9.8% adopted and used 4D BIM 'immediately', i.e. within the same year of recorded first awareness.

‘Postponed-adoption’ is an innovation concept from Emmitt (1997), and for modular-technological-process innovations, this could involve the need to wait for the next-, or target a suitable future-, project before adopting. This was described variously by Participant 189: *“you maybe come across a project where you think ‘oh, this innovation might work for that’, but it is very ad-hoc*”, and then by Participant 123: “*it’s just trying to find the right opportunities to bring them to use.* [A project] *might come in tomorrow but it might not be for 2 years, where I can actually see a use for it*”.[9] Alternatively ‘gradual-adoption’, a new concept introduced here, may occur. This involves trialling the innovation[10] on selected projects before rolling it out further, perhaps in an extended trial. In this outcome, trials are conducted without commitment to fully adopt the innovation, yet if organic organisational adoption occurs then the innovation becomes part of accepted practice. Reinforcing this, Participant 41 provides example of how gradual adoption occurs, and how it is constrained by sector norms:

> *“We tend to want to trial innovations on one project … we get this long cycle where we develop an innovation, we trial it on a project for between 12-24 months, and only at the end do you gain the learning. Then they probably want to trial it on 4 or 5* [other] *projects simultaneously. At the end of those it may then get rolled out across the business, so its anywhere between 2-4 years to deliver an innovation across the whole workplace. The reason that this ends up happening, is that profit margins are quite low, and we are a very risk adverse industry. Those two things combined with long lifecycles mean that innovation is … it’s not stifled but it is extremely hard to drive through, and because we’ve never done dramatic change, it’s very much tiny incremental steps because of the risk involved, so it slows the effect, and that’s an industry-wide thing”.*

If conversely, the decision is to reject the innovation, or do nothing, then ‘passive-rejection’ most typically occurs. Rarer outcome types include ‘immediate-adoption’,

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[9] Several participants considered how the ‘innovation source’, impacts upon the timing of when an innovation is adopted. Participant 123: “*its subcontractors and suppliers that are bringing these new ‘products’ to the market, so it’s trying to find the right project to get them implemented on*”.

[10] And with a Fisher’s Exact Test Statistics of .005, the significance of being able to trial innovations within the sector was previously established and discussed in Gledson and Greenwood (2017).

and 'outright rejection', although these appear infrequent with modular-technological-process innovations. To reinforce how rare 'outright rejection' is, attention is drawn to results in a complementary study (Gledson and Greenwood (2017) against question '*Please confirm if a decision has been made to adopt or reject the use of 4D BIM for the planning of construction work*'. Of three response options offered: 'adopt', 'reject' and 'undecided/no decision made'. Only 1% of respondents, confirmed definite 'reject' decisions. Hence, regarding innovation diffusion, it can be determined that for modular-technological-process innovations 'passive rejection' i.e. making no definitive adopt/reject decision, occurs more frequently than outright rejection decisions. It's also true that when a 'passive rejection' outcome occurs, this may be followed by later gradual-, or postponed-, adoption outcomes.

In addition to decision outcome types, this related study reveals a further factor of organisational size, which affects the firmness of the actual decisions made within the 'decision' IDP stage. Gledson and Greenwood (2017) reveal that for *modular-technological-process innovations*, the most frequent type of adoption-decisions made are 'authority decisions' (by organisational upper management), followed by 'collective decisions' (by consensus), with the least frequent being 'optional decisions'. In that work, bivariate analysis demonstrated associations between company size and the types of organisational decisions made[11], revealing that innovation adoption decisions in larger companies (250 persons+) are much more likely to require 'authority-decisions'. For 4D BIM these researchers also established that, there is more likely to be personal use of 4D BIM within larger companies[12]. One inference drawn from this complementary work is that a definite 'authority-decision' within organizations, leads to quicker personal adoption/use of the innovation by staff members[13]. These definite 'authority-decisions' within larger companies were referred to throughout by participants working for such companies, several of whom, also implied gradual-, or postponed-, adoption for 4D BIM:

- "*They definitely said yes we are going to adopt it*" (Participant 203).
- "*The initial decision was to adopt it. It wasn't ever rejected*" (Participant 41).

[11] Resulting in a Fishers Exact test statistic of .019.
[12] Fishers Exact test statistic of .001.
[13] Though Gledson (2016) reports that despite such definite 'authority decisions' being made by large organisations, variances still exist between individuals in terms of adoption/use.

- "*The corporate decision was to adopt … to commit the resources and time necessary, because of the recognition we needed to do it to remain competitive*" (Participant 189).
- "*The decision was made that it was useful, and we would develop it further*" (Participant 123).

In contrast, analysis also revealed how smaller and medium sized decisions can be more flexible to offering 'immediate-adoption' decisions: "*After* [principal] *first used it … it became an adoption decision. Because he ran the company, it's a small company, he could make the decision quickly*" (Participant 245). However, the data also show how decisions can be less firm, producing 'passive-rejection' outcomes, and slowing levels of individual adoption and use: "*It definitely wasn't a rejection, but it was very, almost an arm's length thing, they kind of just let me get on with it, they paid for the software and the training course* […] *and it was 'oh yes, that seems like a good idea'. It wasn't rejected outright, but it also wasn't adopted by the group. Just, something where they said "yeah, ok, you go away and do it'*" (Participant 100).

Implementation

If the decision is to adopt a modular-technological-process innovation, this will be followed by (V) *implementation*, where the process of the innovation being used, begins via either full adoption, or by trial. Rogers (2003) confirms this process continues until the innovation is institutionalised, no longer being considered as new/distinct from regular business operations. Success at implementation stage is subject to much organisational uncertainty, not least because those who have made decisions to implement, are often different from the implementers. It's important to note that though organisational attributes appear to be more important that individual attributes, implementers themselves should not be considered to be mere passive acceptors of innovation-decisions. Whilst there may be enthusiastic adopters, there may also be those that resent being directed to adopt an innovation, therefore seeking to challenge or discredit it.

Whilst 4D BIM adopters have shown appreciation and enthusiasm for its benefits, a related exploratory case study (Gledson 2016) undertaken during an implementation stage following an authority-decision (that all future company projects use BIM), revealed fears and concerns of organisational staff reinforced in this round of interviews. Specifically, that in terms of general innovation implementation: there are people issues in terms of individual abilities to use, and commitment toward, such innovations[14]; that productivity reduces during learning curves[15] (may not be recognised, or understood by upper management); and that use of such innovations creates additional work requiring additional resource)[16]. Additionally, analysis reveals how innovation implementation can also lead to inefficient effort duplication[17] .

Such concerns reinforce why 'trialability' of modular-technological-process innovations is important, hence this new model also shows additional 'action point': *Trial Innovation*. In construction, trials occur on individual projects, or on a series of projects. For trials to be considered successful they are reviewed post-project, with results, as determined by measurable success criteria, analysed to determine if ongoing adoption continues. Participant 41 explains this, variously describing his prior experiences as a 'change agent' working for a software vendor promoting 4D BIM:

> "[Vendors] *spend a lot of time giving impressions of the provable benefits, and the industry takes them with a pinch of salt, wanting to try for themselves. I found the best way is, you end up trialling on a single pilot project, setting very clear goals of 'this is what success/ failure looks like' and you then score it, as very criteria driven.* [So] *trial it, but if it meets the measured criteria, then it works, there is no need for that middle second phase of 'well let's trial it across 5-10 projects now'.*
>
> *One of the last experiences I had with* [Software Vendor], *we went from doing a couple of very small pilots in isolation to then doing … they called it an extended pilot, but it became the beginnings of a mass roll-out, though it was structured in such a way if that had failed, as part of a larger pilot the roll out would have stopped at the 10 projects. The minute it crossed the 10-project threshold it became*

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[14] "It's culture, you need people who want to try and learn something different, with the correct attitude, who understand the possible benefits … It's just about changing people's attitudes" (Participant 3).
[15] "You've got this learning curve they go through before they become proficient at it and we all start seeing the benefits" (Participant 183).
[16] "It is incredibly resource intensive to develop and then maintain a 4D model" (Participant 208); "4D is great, but it requires intense effort to create and update which makes it a proposition of: 'Is it worth the effort to create and maintain?" (Participant 163)'.
[17] Gledson (2016) illustrates such effort duplication in the hybrid project-delivery processes employed during early BIM innovation adoption.

'this is the way we are doing things from this day forth'. In reality, if you trace it back it was because of this 1 successful pilot project".

It's also expected at this stage that some 're-invention' may occur where an innovation, or its use, may be modified or altered to suit the needs of the various adopters. In this study it was implied that 4D BIM use was 're-invented' by several construction project practitioners for their own purposes: "*it's not just used by planners. It's also used by construction managers, and by the commercial guys, it's used by everyone … It's used by people for different purposes*" (Participant 193). Rogers (2003) advises that such reinvention leads to a faster rate, and higher sustainability of an innovation.

Confirmation

The final stage (VI), *confirmation* occurs when a DMU tries to obtain 'reinforcement' regarding made decisions, although it is possible that seeking such reinforcement may lead to subsequent rejection of the innovation because of new information. This model shows two further enhancements here. The first addition identifies that 'reinforcement messages' are sought by the DMU at this stage to supplement any prior innovation information messages received. The second addition is the 'action point': *Measure*, referring to the measurement of data relevant to predetermined success criteria. These, along with the means of measurement, should be devised at implementation stage.

For 4D BIM, the importance of undertaking such measurement during trialling was revealed[18] Unfortunately, at the time of the study, because of project duration timescales, few if any, organisations seemed to have moved beyond implementation stage, to the confirmation stage, though some had begun to consider means of measurement: "*We are not at the stage of being able to measure benefits of it. We are just on the learning curve of how to implement it. I would say that once we have completed that learning curve, then we can start measuring output data, and see if it has improved against our traditional output data […] Until we implement 4D regularly we won't be able to measure it and do a comparison*" (Participant 15).

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[18] See earlier comment by Participant 41 regarding 'trialability' regarding the importance of: "setting very clear goals of 'this is what success/ failure looks like' and you have to score it, but it has to be very criteria driven … [so] its - trial it, but if it meets the measured criteria then it works".

Conclusion.

Construction is often criticised for poor project delivery, for not innovating, and for not delivering the types of process improvements seen in other industries. However, there is now evidence that parts of the sector have begun to address these concerns and improve some processes. For example, constructors wishing to improve the time predictability of their projects, and who understand the benefits arising from using 4D BIM could use these findings to manage a more focused adoption and implementation of this innovation type in their construction planning practices. Because, as a minimum, the advantages of being able to communicate the construction plan using 4D methods rather than traditional formats mean that this innovation is worth adopting. Yet whilst there is a maturing knowledge base relating to BIM as an innovation, only some of this concerns issues around its adoption, as related back to classic theory, such as innovation diffusion theory (IDT). For related innovations such as 4D BIM, classified here more broadly as a modular-technological-process innovation, this gap is even more apparent. This study addressed this, presenting an enhanced model of the innovation-decision process specific for the construction sector. This can aid understanding of innovation adoption in the UK construction industry as specific to these innovation types by practitioners, and by scholars. First, explanation and discussion over the importance and use of models to facilitate understanding was provided. Then, the generalisability of Rogers (2003) IDP model, was discussed, whilst highlighting construction-centric criticisms of it. Finally, Rogers IDP model was built upon, adding stages, decision-action points, and outcomes, to produce an enhanced model specifically for modular-technological-process innovations in the construction sector. These enhancements were explained, and verified using the results of a multi-stage, mixed-method, research programme. In this way, the objective of using a 4D BIM study to develop a model that further informs innovation diffusion theory was addressed. This new model can assist practitioners in their future adoption/rejection decisions for any such modular-technological-process innovations. For scholars, by extending generic attributes of the IDP model into a construction specific context, it provides greater relevance and also addresses the need for a construction specific model via its theoretical extensions. In addition to these enhancements, this model also reinforces, both for scholars, and practitioners, the importance of existing diffusion concepts of compatibility and trialability, for such innovation types.

Limitations

The overall research programme was a mixed-method study informed by a pragmatist philosophy combining qualitative findings from an initial case study, with quantitative findings from two structured questionnaires, and this final round of semi-structured interviews providing the present qualitative data. The limitation with the greatest potential impact relates to the sampling frame used for the quantitative parts of the prior stages of this study. Instead, because this final stage focused on persons interested in the subject matter, purposive sampling methods were used. These final interviews were held with persons assessed as being suitable, who, having completed the second questionnaire, had therein also signalled willingness to participate in follow-up interviews. From a pragmatist perspective, in mixed methods research such participant selection is not considered a weakness. However, if the quantitative elements only were considered in isolation, use of the non-probability sampling frame may lead readers to believe the ability to make any generalisations[19] at all about this population is restricted. Also from the pragmatist perspective, but as regards the integrity of the conclusions, this work has achieved pragmatic validity (Worren *et al.* 2002), and its context relevant findings are ecological valid. Over the course of the mixed-method research programme, such pragmatic validity was also achieved using strategies of triangulation and member-checking to verify the credibility, transferability, and dependability of the findings. In doing so, the study achieved its ultimate aim of developing a more relevant model for the construction sector, and its actors.

Future research recommendations

To advance this research, efforts should concentrate on the IDT contributions made. Subsequent research focussing on modular-technological-process innovations could make use of the enhanced innovation-decision process model, applying, testing, or further validating it. Any focus on the initial exposure and exploration stages, using

[19] Noting that, whilst in pragmatic science, validity does not contain the same connotations as in pure quantitative research, aside from generalisability, discussions of validity from a purely (post)positivist quantitative research perspective usually discuss other facets such as measurement-, internal-, and external-, validity. An excellent account of (post)positivist validity in the construction domain is provided in the work of Karakhan and Gambatese (2017) and Zhang and Mohandes (2020).

qualitative methods, could generate further knowledge about these. Efforts directed toward the decision, implementation and confirmation stages remain equally important. Similarly, the five decision-outcome types discussed in this model also warrant further research, and survey research could reveal more about the frequency, and reasons behind these types. Organisational efforts to trial, measure benefits, and capture learning around such innovations, would be valued and potentially being achieved through case study research.

References

Aouad, G., Ozorhon, B., and Abbott, C., 2010. Facilitating innovation in construction: Directions and implications for research and policy. *Construction Innovation: Information, Process, Management*, 10 (4), 374–394.

Baccarini, D., 1996. The concept of project complexity—a review. *International Journal of Project Management*, 14 (4), 201–204.

Barrett, P. and Sexton, M., 2006. Innovation in Small, Project-Based Construction Firms*. *British Journal of Management*, 17 (4), 331–346.

Bass, F.M., 1969. A newproduct growth for model consumer durables. *Management Science*, 15 (5), 215–227.

Bass, F.M., 2004. Comments on “A New Product Growth for Model Consumer Durables The Bass Model”. *Management Science*, 50 (12), 1833–1840.

Bertelsen, S., 2003. Construction as a complex system. *In*: *proceedings of IGLC*.

Brewer, G. and Gajendran, T., 2012. Attitudes, behaviours and the transmission of cultural traits: Impacts on ICT/BIM use in a project team. *Construction Innovation: Information, Process, Management*, 12 (2), 198–215.

Buchmann-Slorup, R. and Andersson, N., 2010. BIM-based scheduling of construction–a comparative analysis of prevailing and BIM-based scheduling processes. *In*: *Proceedings of the CIB W78 2010: 27th International Conference*. Cairo, 16–18.

Caerteling, J.S., Halman, J.I.M., Song, M., Dorée, A.G., and Van Der Bij, H., 2013. How Relevant Is Government Championing Behavior in Technology Development? *Journal of Product Innovation Management*, 30 (2), 349–363.

Crotty, R., 2012. *The Impact of Building Information Modelling: Transforming Construction*. Oxon: SPON Press.

Dainty, A., Leiringer, R., Fernie, S., and Harty, C., 2017. BIM and the small construction firm: a critical perspective. *Building Research and Information*, 45 (6), 696–709.

Davies, R. and Harty, C., 2013. Implementing 'Site BIM': A case study of ICT innovation on a large hospital project. *Automation in Construction*, 30, 15–24.

Dodgson, M. and Gann, D., 2010. *Innovation*. Oxford: Oxford University Press.

Dubois, A. and Gadde, L.-E.L.-E., 2002. The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction Management and Economics*, 20 (7), 621–31.

Edwards, G., 2014. Infectious Innovations? The Diffusion of Tactical Innovation in Social Movement Networks, the Case of Suffragette Militancy. *Social Movement Studies*, 13 (1).

Egan, J., 1998. *Rethinking Construction. The report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction*. Construction. London: HMSO.

Egbu, C.O., 2004. Managing knowledge and intellectual capital for improved organizational innovations in the construction industry: an examination of critical success factors. *Engineering, Construction and Architectural Management*, 11 (5), 301–315.

Elghaish, F. and Abrishami, S., 2020. Developing a framework to revolutionise the 4D BIM process: IPD-based solution. *Construction Innovation*, 20 (3), 401–420.

Emmitt, S., 1997. The Diffusion of Innovations in the Building Industry. University of Manchester.

Farmer, M., 2016. *The Farmer Review of the UK Construction Labour Model: Modernise or Die*.

Fox, S. and Hietanen, J., 2007. Interorganizational use of building information models: potential for automational, informational and transformational effects. *Construction Management and Economics*, 25 (3), 289–296.

Gambatese, J.A. and Hallowell, M., 2011. Factors that influence the development and diffusion of technical innovations in the construction industry. *Construction Management and Economics*, 29 (5), 507–517.

Gann, D. and Salter, A.J., 2000. Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy*, 29 (7–8), 955–972.

Georgiadou, M.C., 2019. An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. *Construction Innovation*, 19 (3), 298–320.

Gledson, B., 2016. Hybrid project delivery processes observed in constructor BIM innovation adoption. *Construction Innovation*, 16 (2), 229–246.

Gledson, B. and Greenwood, D., 2016. Surveying the extent and use of 4D BIM in the UK. *Journal of Information Technology in Construction (ITcon)*, 21 (April), 57–71.

Gledson, B. and Greenwood, D., 2017. The adoption of 4D BIM in the UK construction industry: an innovation diffusion approach. *Engineering, Construction and Architectural Management*, 24 (6), 950–967.

Glenigan, 2018. *UK Industry Performance Report 2018. Based on the UK Construction Industry KPI's*.

Goldenberg, J. and Oreg, S., 2007. Laggards in disguise: Resistance to adopt and the leapfrogging effect. *Technological Forecasting and Social Change*, 74 (8), 1272–1281.

Green, S. and May, S.C., 2005. Lean construction: arenas of enactment, models of diffusion and the meaning of 'leanness'. *Building Research & Information*, 33 (6), 498–511.

Harty, C., 2005. Innovation in construction: a sociology of technology approach. *Building Research & Information*, 33 (6), 512–522.

Harty, C., 2008. Implementing innovation in construction: contexts, relative boundedness and actor-network theory. *Construction Management and Economics*, 26 (10), 1029–1041.

HM Government, 2013. *Construction 2025. Industrial Strategy: government and* *industry in partnership*. London.

HM Government, 2017. *Industrial Strategy: Building a Britain fit for the future*. London, England.

Hosseini, M.R.R., Chileshe, N., Zuo, J., and Baroudi, B., 2015. Adopting global virtual engineering teams in AEC Projects: A qualitative metaanalysis of innovation diffusion studies. *Construction Innovation: Information, Process, Management*, 15 (2), 151–179.

IGT, 2010. *Low Carbon Construction*. Innovation. Department for Business, Innovation and Skills.

Johnson, R. and Onwuegbuzie, A.J., 2004. Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, 33 (7), 14–26.

Kale, S. and Arditi, D., 2005. Diffusion of Computer Aided Design Technology in Architectural Design Practice. *Journal of Construction Engineering and Management*, 131, 1135–1141.

Kale, S. and Arditi, D., 2006. Diffusion of ISO 9000 certification in the precast concrete industry. *Construction Management and Economics*, 24 (5), 485–495.

Kale, S. and Arditi, D., 2010. Innovation Diffusion Modeling in the Construction Industry. *Journal of Construction Engineering and Management*, 136 (3), 329–340.

Kassem, M., Iqbal, N., Kelly, G., Lockley, S., and Dawood, N., 2014. BUILDING INFORMATION MODELLING : COLLABORATIVE DESIGN PROCESSES PROTOCOLS. *ITcon*, 19 (July), 126–149.

Kastelle, T. and Steen, J., 2011. Ideas are not innovations. *Prometheus*, 29 (2), 199–205.

Koo, B. and Fischer, M., 2000. Feasibility Study of 4D CAD in Commercial Construction. *Journal of Construction Engineering and Management*, 126 (4), 251–260.

Koskela, L. and Vrijhoef, R., 2001. Is the current theory of construction a hindrance to innovation? *Building Research & Information*, 29 (3), 197–207.

Larsen, G.D., 2005. Horses for courses: relating innovation diffusion concepts to the stages of the diffusion process. *Construction Management and Economics*, 23 (8), 787–792.

Larsen, G.D., 2011. Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks. *Construction Management and Economics*, 29 (10), 987–1002.

Larsen, G.D. and Ballal, T.M. a., 2005. The diffusion of innovations within a UKCI context: an explanatory framework. *Construction Management and Economics*, 23 (1), 81–91.

Latham, M., 1994. Constructing the team: final report.

Li, H., Lu, W., and Huang, T., 2009. Rethinking project management and exploring virtual design and construction as a potential solution. *Construction Management and Economics*, 27 (4), 363–371.

Li, X., Wu, P., Shen, G.Q., Wang, X., and Teng, Y., 2017. Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. *Automation in Construction*, 84 (July), 195–206.

Lindgren, J. and Emmitt, S., 2017. Diffusion of a systemic innovation A longitudinal case study of a Swedish multi-storey timber housebuilding system. *Construction Innovation*, 17 (1), 25–44.

Liston, K., Fischer, M., and Winograd, T., 2001. Focused sharing of information for multidisciplinary decision making by project teams. *ITCon*, 6, 69–82.

Loosemore, M., 2014. *Strategic Risk in Construction: Turning Serendipity Into Capability*. Abingdon, Oxon.: Routledge.

Loosemore, M. and Richard, J., 2015. Valuing innovation in construction and infrastructure. *Engineering Construction & Architectural Management*, 22 (1), 38–53.

Love, P.E.D., Edwards, D.J., Han, S., and Goh, Y.M., 2011. Design error reduction: toward the effective utilization of building information modeling. *Research in Engineering Design*, 22 (3), 173–187.

Mahalingam, A., Kashyap, R., and Mahajan, C., 2010. An evaluation of the applicability of 4D CAD on construction projects. *Automation in Construction*, 19 (2), 148–159.

McKinsey Global Institute, 2017. *Reinventing Construction: A Route To Higher Productivity*. McKinsey & Company.

Miozzo, M. and Dewick, P., 2004. *Innovation in construction: a European analysis.* Edward Elgar Publishing.

Moore, G.A., 2014. *Crossing the Chasm, 3rd Edition*. HarperCollins.

Morgan, D.L., 2007. Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. *Journal of Mixed Methods Research*, 1 (1), 48–76.

Murphy, M.E., Perera, S., and Heaney, G., 2015. Innovation management model: a tool for sustained implementation of product innovation into construction projects. *Construction Management and Economics*, 33 (3), 209–232.

Myers, D., 2013. *Construction Economics: A New Approach*. 3rd ed. Oxon: Routledge.

Na Lim, J., 2014. The Government as marketer of innovation. *Engineering, Construction and Architectural Management*, 21 (5), 551–570.

ONS, 2016. Construction Statistics Annual Table [online]. *Office of National Statistics (ONS)*. Available from: http://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/con structi onstatisticsannualtables [Accessed 21 Sep 2016].

Panuwatwanich, K., Stewart, R.A., and Mohamed, S., 2009. Critical pathways to enhanced innovation diffusion and business performance in Australian design firms. *Automation in Construction*, 18 (6), 790–797.

Park, M., Nepal, M.P., and Dulaimi, M.F., 2004. Dynamic modeling for construction innovation. *Journal of Management in Engineering*, 20 (4), 170–177.

Peansupap, V. and Walker, D., 2005. Exploratory factors influencing information and communication technology diffusion and adoption within Australian construction organizations: a micro analysis. *Construction Innovation Information Process Management*, 5 (3), 135–157.

Poirier, E., Staub-French, S., and Forgues, D., 2015. Embedded Contexts of Innovation: BIM Adoption and Implementation for a Specialty Contracting SME. *Construction Innovation: Information, Process, Management*, 15 (1), 42–65.

Raftery, J., 1998. From Ptolemy to Heisenberg: quantitative models and reality. *Construction Management & Economics*, 16 (3), 295–302.

Reichstein, T., Salter, A.J., and Gann, D., 2005. Last among equals: a comparison of innovation in construction, services and manufacturing in the UK. *Construction Management and Economics*, 23 (6), 631–644.

Rogers, E.., 2003. *Diffusion of Innovations*. 5th ed. New York, N.Y.: Free Press, Simon & Schuster.

Sacks, R., Eastman, C.M., Lee, G., and Teicholz, P., 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*. 3rd ed. Hoboken, New Jersey: Wiley.

Shibeika, A. and Harty, C., 2015. Diffusion of digital innovation in construction: a case study of a UK engineering firm. *Construction Management and Economics*, 33 (5–6), 453–466.

Slaughter, E., 1998. Models of Construction Innovation. *Journal of Construction Engineering and Management*, 124 (3), 226–231.

Slaughter, E., 2000. Implementation of construction innovations. *Building Research & Information*, 28 (1), 2–17.

Succar, B., 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18 (3), 357–375.

Succar, B., Sher, W., and Williams, A., 2012. Measuring BIM performance : Five metrics. *Architectural Engineering and Design Management*, 8 (2), 120–142.

Taylor, J. and Levitt, R., 2004. *A new model for systemic innovation diffusion in project-based industries*. Project Management Institute International Research Conference. London, England, No. CIFE Working Paper #WP086.

Taylor, J.E., Levitt, R.E., and Fellow, L.G., 2004. Understanding and managing systemic innovation in project-based industries. *In*: D. Slevin, D. Cleland, and J. Pinto, eds. *Innovations: Project Management Research 2004*. Newtown Square, PA: Project Management Institute, 83–99.

Tizani, W., 2007. Engineering Design. *In*: G. Aound, A. Lee, and S. Wu, eds. *Constructing the future: nD modelling*. New York: Taylor & Francis, 14–39.

Trebbe, M., Hartmann, T., and Dorée, A., 2015. 4D CAD models to support the coordination of construction activities between contractors. *Automation in Construction*, 49, 83–91.

Waly, A. and Thabet, W., 2003. A virtual construction environment for preconstruction planning. *Automation in Construction*, 12, 139–154.

Widén, K. and Hansson, B., 2007. Diffusion characteristics of private sector financed innovation in Sweden. *Construction Management and Economics*, 25 (5), 467–475.

Williams, T.., 1999. The need for new paradigms for complex projects. *International Journal of Project Management*, 17 (5), 269–273.

Winch, G., 1998. Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, 26 (5), 268–279.

Winch, G., 2003. How innovative is construction? Comparing aggregated data on construction innovation and other sectors – a case of apples and pears. *Construction Management and Economics*, 21 (6), 651–654.

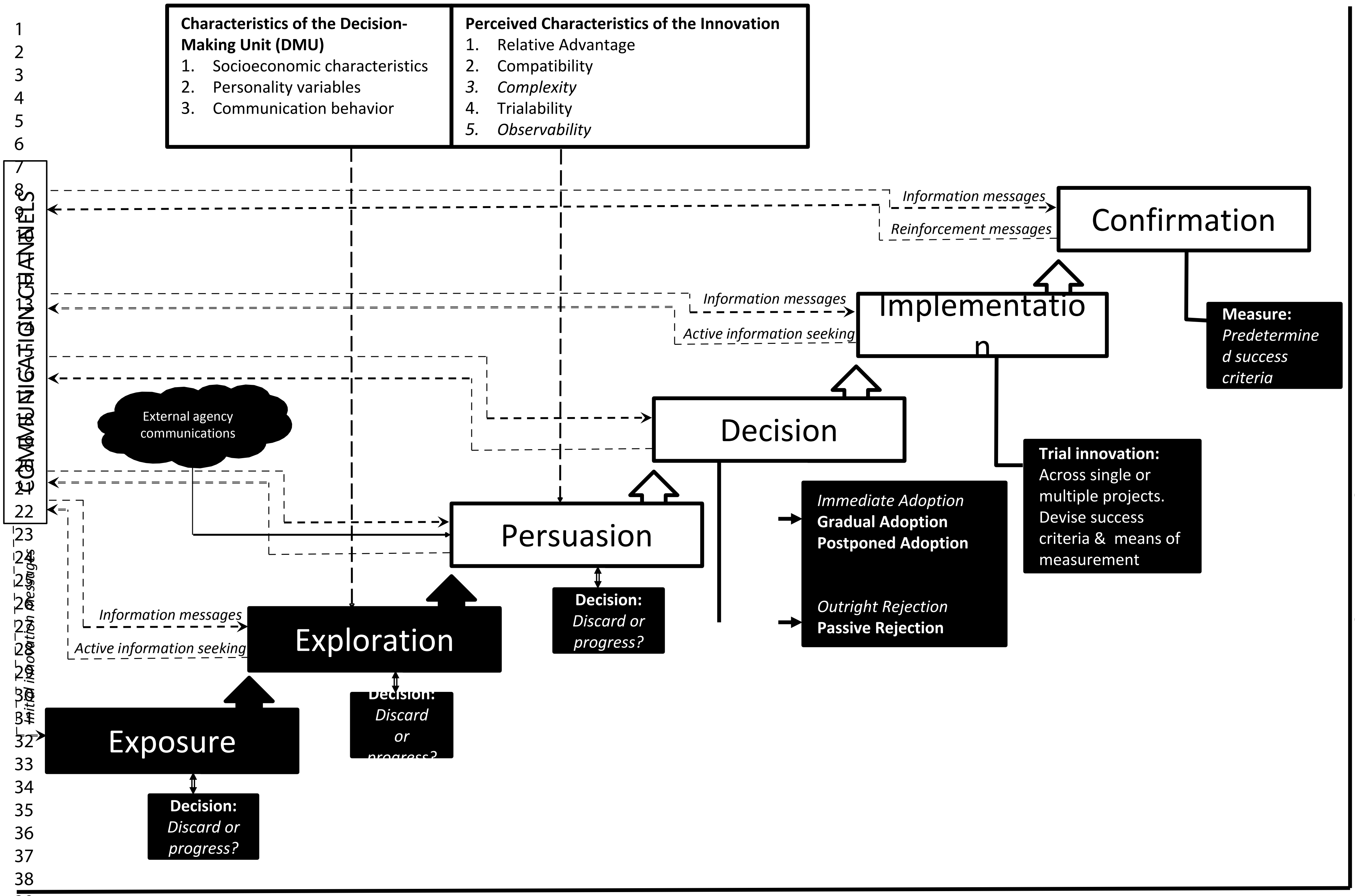
Windahl, S., Signitzer, B., and Olson, J.T., 2008. *Using communication theory: An introduction to planned communication*. Sage.

Wolstenholme, A., 2009. Never Waste a Good Crisis.

Worren, N., Moore, K., and Elliott, R., 2002. When theories become tools: Toward a framework for pragmatic validity. *Human Relations*, 55 (10), 1227–1250.

Table 1: Construction time predictability for years 2009–2018, percentage of projects and phases delivered on time or better. Adapted from Glenigan (2018)

KPI	2009	2010	2011	2012	2013/14	2015	2016	2017	2018	10yr Ave.
Predictability Time: Project	45	43	45	34	45	40	41	66	63	47
Predictability Time: Design	53	69	51	48	52	53	48	53	53	53
Predictability Time: Construction	59	57	60	42	67	48	55	67	59	58


Characteristics of the Decision-Making Unit (DMU)
1. Socioeconomic characteristics
2. Personality variables
3. Communication behavior
Perceived Characteristics of the Innovation
1. Relative Advantage
2. Compatibility
3. Complexity
4. Trialability
5. Observability
COMMUNICATION CHANNELS
Information messages
Reinforcement messages
Confirmation
Information messages
Active information seeking
Implementation
Measure:
Predetermined success criteria
External agency communications
Decision
Trial innovation:
Across single or multiple projects.
Devise success criteria & means of measurement
Persuasion
Immediate Adoption
Gradual Adoption
Postponed Adoption
Outright Rejection
Passive Rejection
Information messages
Active information seeking
Exploration
Decision:
Discard or progress?
Initial innovation messages
Exposure
Decision:
Discard or
Decision:
Discard or progress?
Time
Progression through Innovation Decision Process

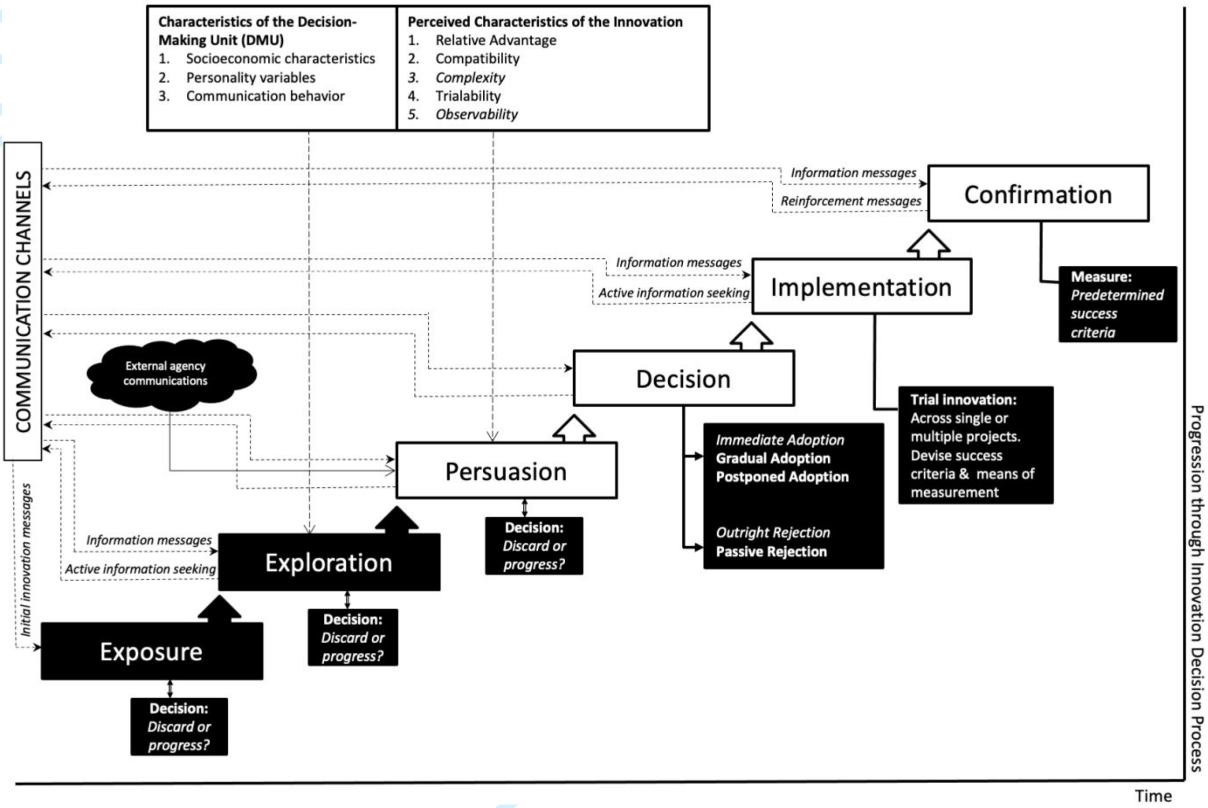


Figure 1: Enhanced model of the innovation-decision process for modular-technological-process innovations in construction.

Research Stage	Participant ID	Sex	Age/Age Range	Professional Function	Job Level
Case Study Interviews (19 Participants)	1	F		Company Director	Company Director level
	2	M		Design Manager	Middle management level
	3	M		QS	Middle management level
	4	M		Construction Project Manager	Senior management level
	5	M		Planner	Middle management level
	6	M		Construction Project Manager	Senior management level
	7	F		Planner	Middle management level
	8	M		Other Consultant Professional	Company Director level
	9	M		Other Consultant Professional	Senior management level
	10	F		Business Development Company Director	Company Director level
	11	M		Architect	Senior management level
	12	M		Other Consultant Professional	Senior management level
	13	M		Technical Specialist (i.e Planner; QS; Digital Engineer)	Senior management level
	14	M		Software Vendor	Senior management level
	15	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	16	M		Technical Specialist (i.e Planner; QS; Digital Engineer)	
	17	M		Other Consultant Professional	
	18	M		Digital Engineer	Lower management
	19	M		Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
Exploratory Questionnaire (136 responses)	20	M	30-34	Planner	Academic
	21	F	40-44	Other (Please Clarify Below)	Academic
	22	F	30-34	Design Manager	Middle management level
	23	M	60-64	Other Consultant Professional	Senior management level
	24	M	25-29	Planner	Middle management level
	25	M	50-54	Planner	Middle management level
	26	M	35-39	Planner	Middle management level
	27	M	35-39	Design Manager	Middle management level
	28	M	45-49	Planner	Senior management level
	29	M	30-34	Other Consultant Professional	Middle management level
	30	M	30-34	Planner	Middle management level
	31	F	40-44	Planner	Middle management level
	32	M	30-34	Planner	Middle management level
	33	M	40-44	Planner	Middle management level
	34	F	25-29	Design Manager	Senior management level
	35	M	60-64	Planner	Middle management level
	36	M	55-59	Consultant Project Manager (i.e. client side)	Senior management level
	37	M	50-54	Company Director Level at Construction Firm	Company Director level
	38	F	35-39	Planner	Senior management level
	39	M	25-29	Other (Please Clarify Below)	Other
	15	M	18-24	Planner	Middle management level
	40	M	25-29	Site Manager	Middle management level
	41	M	30-34	Company Director Level at Consultant Firm	Senior management level
	42	M	45-49	Company Director Level at Construction Firm	Company Director level
	43	M	35-39	Other (Please Clarify Below)	Senior management level
	44	M	60-64	Other (Please Clarify Below)	Senior management level
	45	M	50-54	Construction Project Manager (single project)	Middle management level
	46	M	40-44	Company Director Level at Consultant Firm	Senior management level
	47	M	35-39	Planner	Graduate management level
	16	M	25-29	Planner	Middle management level
	48	M	30-34	Quantity Surveyor	Senior management level
	49	M	40-44	Architect	Company Director level
	50	M	18-24	Architectural Technologist	Graduate management level
	51	M	35-39	Other (Please Clarify Below)	Other
	52	M	18-24	Other Consultant Professional	Other

Research Stage	Participant ID	Sex	Age/Age Range	Professional Function	Job Level
	53	M	55-59	Other (Please Clarify Below)	Company Director level
	54	M	25-29	Architectural Technologist	Senior management level
Exploratory Questionnaire (136 responses)	55	M	30-34	Other (Please Clarify Below)	Middle management level
	56	M	25-29	Planner	Middle management level
	57	F	18-24	Site Engineer	Graduate management level
	58	M	25-29	Site Manager	Middle management level
	59	M	25-29	Graduate/Trainee Level	Graduate management level
	60	M	30-34	Other (Please Clarify Below)	Senior management level
	61	M	25-29	Architect	Graduate management level
	62	M	40-44	Services Engineer	Academic
	63	M	40-44	Construction Manager (across multiple projects)	Senior management level
	64	M	35-39	Structural Engineer	Senior management level
	65	M	25-29	Construction Project Manager (single project)	Middle management level
	66	M	40-44	Planner	Middle management level
	67	M	35-39	Planner	Middle management level
	68	M	35-39	Architectural Technologist	Middle management level
	69	M	60-64	Planner	Senior management level
	70	M	18-24	Other (Please Clarify Below)	Middle management level
	71	M	35-39	Other Consultant Professional	Senior management level
	72	M	25-29	Design Manager	Middle management level
	73	M	45-49	Other (Please Clarify Below)	Academic
	74	F	under 18	Architect	Other
	75	M	25-29	Consultant Project Manager (i.e. client side)	Graduate management level
	76	M	25-29	Site Engineer	Graduate management level
	77	M	30-34	Planner	Senior management level
	78	M	45-49	Planner	Middle management level
	79	M	25-29	Services Engineer	Graduate management level
	80	F	18-24	Other Consultant Professional	Middle management level
	81	M	35-39	Other Consultant Professional	Company Director level
	82	M	25-29	Planner	Middle management level
	83	M	25-29	Graduate/Trainee Level	Graduate management level
	84	M	25-29	Planner	Senior management level
	85	F	18-24	Other Consultant Professional	Graduate management level
	86	M	25-29	Other Consultant Professional	Graduate management level
	87	M	45-49	Other Design Professional	Middle management level
	88	M	25-29	Design Manager	Middle management level
	89	M	45-49	Architectural Technologist	Senior management level
	90	M	35-39	Services Engineer	Senior management level
	91	M	40-44	Construction Manager (across multiple projects)	Senior management level
	92	F	30-34	Architect	Middle management level
	93	M	30-34	Design Manager	Middle management level
	94	M	45-49	Design Manager	Senior management level
	95	M	40-44	Other Consultant Professional	Other
	96	M	35-39	Quantity Surveyor	Senior management level
	97	M	18-24	Planner	Graduate management level
	98	M	30-34	Other (Please Clarify Below)	Academic
	99	M	25-29	Planner	Middle management level
	100	M	35-39	Planner	Middle management level
	101	F	40-44	Planner	Company Director level
	102	M	55-59	Planner	Middle management level
	103	M	30-34	Planner	Middle management level
	104	M	55-59	Consultant Project Manager (i.e. client side)	Senior management level
	105	M	30-34	Planner	Middle management level
	106	M	45-49	Planner	Middle management level
	107	M	45-49	Planner	Senior management level
	108	F	30-34	Planner	Middle management level

Research Stage	Participant ID	Sex	Age/Age Range	Professional Function	Job Level
	109	M	40-44	Company Director Level at Construction Firm	Company Director level
	110	F	25-29	Other (Please Clarify Below)	Middle management level
Exploratory Questionnaire (136 responses)	111	M	30-34	Planner	Graduate management level
	112	M	30-34	Design Manager	Middle management level
	113	M	55-59	Planner	Senior management level
	114	M	35-39	Planner	Senior management level
	115	M	18-24	Planner	Academic
	116	M	35-39	Planner	Graduate management level
	117	M	35-39	Planner	Middle management level
	118	M	45-49	Planner	Senior management level
	119	M	45-49	Planner	Senior management level
	120	M	50-54	Planner	Middle management level
	121	M	40-44	Planner	Middle management level
	122	F	25-29	Planner	Senior management level
	123	M	35-39	Planner	Middle management level
	124	M	30-34	Construction Project Manager (single project)	Academic
	125	M	35-39	Planner	Senior management level
	126	M	45-49	Planner	Middle management level
	127	M	45-49	Planner	Middle management level
	128	M	25-29	Planner	Middle management level
	129	M	60-64	Planner	Middle management level
	130	M	30-34	Planner	Middle management level
	131	M	45-49	Planner	Middle management level
	132	F	30-34	Planner	Middle management level
	133	F	25-29	Planner	Middle management level
	134	M	50-54	Company Director Level at Construction Firm	Company Director level
	135	M	35-39	Planner	Middle management level
	136	M	50-54	Construction Manager (across multiple projects)	Senior management level
	137	M	40-44	Construction Manager (across multiple projects)	Senior management level
	138	M	45-49	Planner	Middle management level
	139	M	18-24	Planner	Graduate management level
	140	M	45-49	Construction Project Manager (single1 project)	Middle management level
	141	M	30-34	Design Manager	Middle management level
	142	M	55-59	Planner	Middle management level
	143	M	35-39	Design Manager	Middle management level
	144	M	45-49	Planner	Senior management level
	145	F	45-49	Planner	Middle management level
	146	M	55-59	Planner	Senior management level
	147	M	45-49	Consultant Project Manager (i.e. client side)	Senior management level
	148	M	18-24	Design Manager	Graduate management level
	149	F	40-44	Planner	Middle management level
	150	M	55-59	Company Director Level at Consultant Firm	Company Director level
	151	M	45-49	Planner	Senior management level
	152	M	45-49	Planner	Senior management level
	153	M	60-64	Planner	Senior management level
Explanatory Questionnaire (97 Responses)	154	M	30	Management Professional	Upper management level
	155	M	28	Management Professional	Lower management
	156	M	31	Management Professional	Middle management level
	157	M	30	Management Professional	Middle management level
	135	M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	53	M	59	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	41	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	15	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	158	F	26	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	113	M	58	Management Professional	Upper management level

Research Stage	Participant ID	Sex	Age/Age Range	Professional Function	Job Level
	159	M	37	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	160	F	44	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
Explanatory Questionnaire (97 Responses)	161	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	162	M	35	Design Professional	Lower management
	163	M	47	Management Professional	Middle management level
	164	M	42	Management Professional	Middle management level
	165	M	50	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	166	M	34	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	167	M	50	Management Professional	Upper management level
	168	M	44	Management Professional	Middle management level
	169	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	170	M	43	Management Professional	Upper management level
	171	M	60	Management Professional	Middle management level
	172	M	27	Management Professional	Lower management
	173	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	174	M	42	Management Professional	Upper management level
	175	M	39	Management Professional	Upper management level
	176	M	44	Design Professional	Upper management level
	177	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	178	M	25	Management Professional	Middle management level
	179	M	40	Management Professional	Middle management level
	180	M	32	Management Professional	Lower management
	181	M	44	Management Professional	Middle management level
	182	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	183	F	38	Management Professional	Middle management level
	184	M	56	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	185	M	39	Management Professional	Lower management
	186	M	44	Management Professional	Middle management level
	187	M	50	Management Professional	Lower management
	188	M	59	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	189	M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	190	M	35	Management Professional	Upper management level
	191	F	27	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	192	M	42	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	193	M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	194	M	27	Management Professional	Middle management level
	195	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	123	M	40	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	196	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	197	M	47	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	198	M	28	Management Professional	Lower management
	199	M	47	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	200	M	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	201	M	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	202	M	61	Design Professional	Middle management level
	203	M	34	Management Professional	Middle management level
	204	M	33	Management Professional	Lower management
	205	F	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	206	M	50	Management Professional	Upper management level
	207	M	43	Management Professional	Upper management level
	208	M	36	Management Professional	Middle management level
	209	M	43	Management Professional	Lower management
	210	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	211	M	50	Management Professional	Upper management level
	212	F	53	Management Professional	Middle management level
	213	M	29	Management Professional	Middle management level

Research Stage	Participant ID	Sex	Age/Age Range	Professional Function	Job Level
	214	M	68	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	215	M	35	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
Explanatory Questionnaire (97 Responses)	216	F	53	Management Professional	Upper management level
	217	M	37	Management Professional	Middle management level
	218	F	28	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	219	M	39	Management Professional	Upper management level
	220	M	34	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	221	F	35	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	222	F	27	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	223	M	35	Management Professional	Middle management level
	224	M	38	Management Professional	Upper management level
	225	M	39	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	226	M	22	Design Professional	Lower management
	227	M	35	Management Professional	Upper management level
	228	M	23	Design Professional	Lower management
	229	M	52	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	230	M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	231	M	55	Management Professional	Upper management level
	232	M	38	Management Professional	Upper management level
	233	M	53	Management Professional	Middle management level
	234	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	235	M	39	Management Professional	Upper management level
	236	M	30	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	237	M	42	Management Professional	Lower management
	238	F	32	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	239	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	240	M	25	Management Professional	Lower management
	241	M	39	Management Professional	Upper management level
	242	M	28	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	243	M	61	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	244	M	56	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
Final Stage Interviews (13 Participants)	210	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	245	M	37	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	100	M	35-39	Planner	Middle management level
	203	M	34	Management Professional	Middle management level
	195	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	193	M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	41	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	189	M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level
	15	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management
	123	M	40	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level
	231	M	55	Management Professional	Upper management level
	241	M	39	Management Professional	Upper management level
	246	M	-	Planner	Middle management level

Research Instrument: Semi-Structured Interview Guide

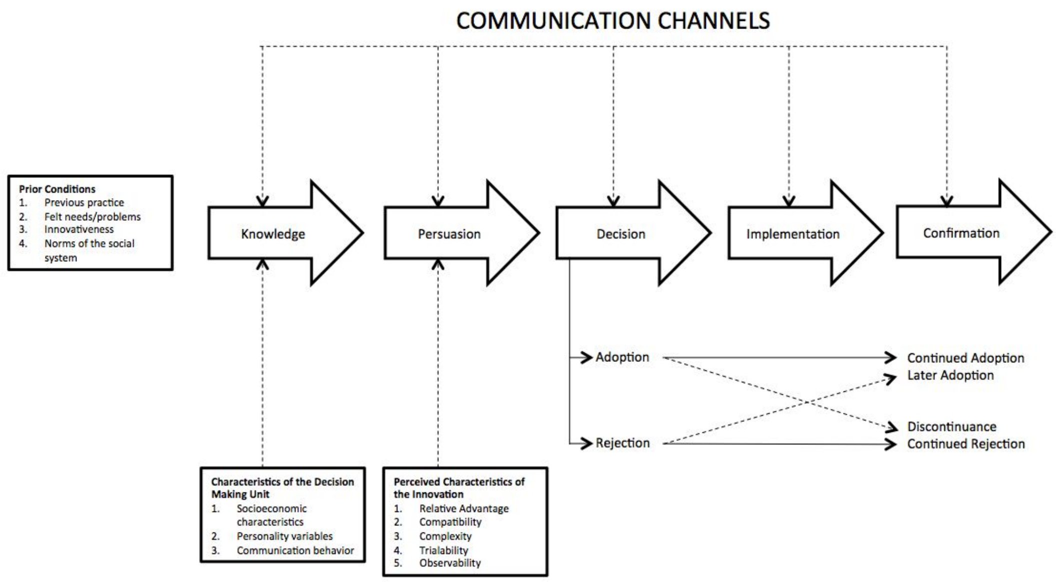
The first few questions 1-3 focus on innovations and the construction industry in general. An innovation is defined as "*an idea, practice or object that is perceived as new by an individual or other unit of adoption*", after that a few questions focus on specific innovations of BIM and 4D BIM. The last question relates to construction project time predictability.

1) What is your assessment of the level of innovation in the construction industry?
2) Does the way that the industry is structured affect the levels of construction innovation?
3) How are industry innovations best implemented?

About BIM in general:

4) Has BIM impacted upon the quality of production information?
5) Has BIM impacted upon the planning of construction work?

The rest of the questions focus particularly on 4D BIM. First please review the below model and text describing the 5 stages of the Innovation decision process.



The innovation-decision-process is the process through which an individual (or other decision-making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision.

6) You identified in the prior questionnaire when you were first aware of 4D BIM and when you first used it (the knowledge (I) and decision (III) stages respectively). I'd like to explore some further aspects of this 'innovation decision' period in line with the above model: For example, (I) what was your initial knowledge of 4D BIM; (II) what persuaded you to consider the use of 4D BIM; (III) what initial decision was made after first use - adoption or rejection; (IV) any issues around the implementation - when it was put into actual practice; and (V) has any confirmation occurred to reinforce the adoption / rejection decision made.

7) On the questionnaire you have already identified the impact of communication channels upon your use of 4D BIM. As a reminder these communication channels are external (such as mass media - internet, literature etc.) and internal (such as interpersonal - face to face exchanges between two or more individuals) communication channels. Could you expand further on your original answers?

8) Key persons involved in any innovation diffusion effort are opinion leaders and change agents. An opinion leader is someone internal to your company or network who provides information and advice about innovations often in an informal role. A 'change agent' is someone external from your company or network who acts as a link between the generators of an innovation and any potential adopters of an innovation. In this instance a change agent may be someone who acted as a link in-between government task force or software vendors and yourself. Can you recall any particular interaction with individuals who fit these descriptions, and how this interaction impacted upon the innovation-decision process?

9) There are always consequences (changes) that occur as a result of adoption or rejection of an innovation I'd like to explore these. Can you tell me of any (I) desirable or undesirable consequences (II) direct or indirect consequences and (III) anticipated or unanticipated consequences of 4D BIM innovation?

10) The UK government has set a target for 2025 that all construction projects are to be delivered 50% faster (from inception to completion) than the industry 2013 performance, where only 45% of projects were delivered on time or better. Do you think the use of 4D BIM can help improve the time predictability of construction projects? And if so how?