Hybrid project delivery processes observed in constructor BIM innovation adoption

Introduction

The focus of innovation diffusion theory often centres on how new ideas or improvements in products, processes or systems transfer and converge between multiple entities (Rogers, 2003). Construction is often accused as being an industry with low levels of innovation (Slaughter, 2000; Winch, 1998); yet more recent discussion has considered how construction has a great deal of incremental 'invisible' innovation (Loosemore, 2014). The introduction of Building Information Modelling (BIM) has been very visible within the construction domain, and the UK Government BIM mandate (HM Government, 2011) arrived during economic recession when strategic organisational decisions of the timing of BIM implementation were influenced by unfavourable prevailing market considerations. The systematic review of innovation diffusion literature undertaken by Hosseini *et al.* (2015) identified core attributes of construction innovations being: new to the implementing institution(s); of a non-trivial change in nature; forecasting process related benefits; generating value to organisational strategic outcomes; providing competitive advantages; subject to much uncertainty and risk; and importing practices from outside of construction. Against such attributes, BIM can be regarded as an innovation. Succar (2009, p357) identified that *"Building Information Modelling (BIM) is an emerging technological and procedural shift within the Architecture, Engineering, Construction and Operations (AECO) industry*". BIM has been classified, both as an innovation (Brewer and Gajendran, 2012; Davies and Harty, 2013a) and as a disruptive technology (Kassem *et al*., 2014; Succar *et al*., 2012). Loosemore (2014) identifies that a disruptive innovation is defined by *"the extent to which it departs from industry norms … renders existing business models obsolete, changes the basis of competition in an industry and produces sustainable competitive advantage by changing the way a whole industry works"*. The most prominent radical, transformative and disruptive innovation to hit construction industry is the use of Building Information Modelling. "*BIM is seen by many as being a disruptive innovation, which is bringing about the reconfiguration of practices in the AEC industry* (Poirier *et al*., 2015). This case study research reports on findings of BIM innovation being diffused into and disrupting the existing working practices of a major contracting organisation. A review of literature pertaining to organisational change, construction innovation and BIM was undertaken, and the general innovation-diffusion process popularised by Rogers (2003) consisting of *Knowledge; Persuasion; Decision; Implementation* and *Confirmation* stages was used for framing the research questions. Empirical data was gathered through qualitative interviews and observations made during the implementation stage of the innovation-decision process (Rogers, 2003).

Organisational change

Senior (2010) identified three categories of organisational change, which are: the rate of occurrence of change, identification of how change manifests itself, and the scale of change. In a review of literature associated with the rate of occurrence of change, Todnem (2005) produced a spectrum ranging from '*discontinuous change*', which are single events resulting in rapid change, through to '*bumpy continuous change*', which are more regular organisational and operational changes with periods of stability disrupted by accelerated changes. Change can manifest itself within an organisation either as planned or emergent change. The planned approach to change is a control oriented top-down approach and the emergent approach is bottom up, more responsive to external and internal environment stimulus and therefore more applicable to construction organisations operating in environments of uncertainty. Notable models of emergent change within the literature include *Ten Commandments for Executing Change* (Kanter *et al*., 2001); *Seven Steps* (Luecke, 2003), and *Eight-Stage Process for Successful Organisational Transformation* (Kotter, 2012). Todenm (2005) identified the scale of change ranges from *fine-tuning/convergent*, *incremental*, *modular* (aka radical) and *corporate*, where organisational mission and values are altered. When considering the adoption of BIM-innovation from the perspective of organisational change theory the rate can be categorised as discontinuous, the approach as emergent and the scale as radical.

There have been frequent attempts from the construction research community to improve construction project performance by advocating the implementation of various process innovations such as greater use of integrated team working and collaboration or through wholesale adoption of lean philosophies and techniques. Previous studies found that much of the problems with the construction industry can be traced back to issues of language and action (Vrijhoef *et al*., 2001), and that process improvement strategies seldom filter down fully to project level practitioners often due to industry '*cultural and motivational difficulties*' (Johansen and Wilson, 2006). Other prominent factors include industry structure and complexity, product and process uncertainty, and the communication networks that envelop collaborations between actors within Temporary Project Organisations (Dubois and Gadde, 2002; Gann and Salter, 2000; Taylor and Levitt, 2004; Winch, 1998). Despite this knowledge, there is belief that the adoption of BIM-innovation can only improve the performance of the construction industry (Crotty, 2012), and the opportunities afforded by BIM have been attractive to a range of leading contracting organisations.

BIM-Innovation

Barlish and Sullivan (2012) noted that initial BIM related research articles surveyed construction practitioners, for their perceptions and definitions, and the use of BIM was reported in relation to other more established factors. For example, Issa and Suermann (2009) gathered data of BIM perceptions relative to the common set of construction key performance indicators (KPI's) of cost, quality, time, safety and productivity. With the body of knowledge increasing literature has emphasised people, process and technology as being the main barriers to implementation (Bew and Underwood, 2009; Owen *et al*., 2010; Rekola *et al*., 2010; Sacks *et al*., 2010), and use of BIM and collaborative techniques has been celebrated as solutions to problems of managing construction project data and information. Related research has identified that the implementation and success of BIM may stagnate due to issues associated with unsatisfactory technological interoperability, which can impede the flow of information through a project lifecycle (Grilo and Jardim-Goncalves, 2010; Stapleton *et al*., 2014).

Work focussing on the benefits of BIM has identified improvements in collaboration (Sebastian, 2011), reduction in the various forms of product and process waste and improvements in design coordination (Eastman *et al*., 2011; Huang *et al*., 2009; Rekola *et al*., 2010) and improved health and safety planning (Li, 2012; Rwamamara *et al*., 2010; Sulankivi *et al*., 2009). Virtual prototyping that allows clash detection is considered as being a key construction benefit (Davies and Harty, 2013a; Poirier *et al*., 2015), as this functionality within BIM platforms allow specifically selected sets of components or objects across multiple models to be run against each other in order to determine any unwanted interference (Hardin, 2009).

Gu and London (2010) asserted that practitioners are not adequately informed to be able to provide sufficient reflection of the necessary pre-requisites within a contracting organisations for the implementation and use of BIM innovation. This is because of a lack of clarity on roles, responsibilities, and the distribution of benefits in adopting BIM, as well as limited understanding, awareness, input and articulation of needs by industry practitioners, which in turn directly inhibits progression and maturity of BIM technologies. These researchers developed a collaborative BIM decision framework to assist practitioners correlate their anticipated BIM adoption requirements with current needs, and found that BIM adoption required changes to four interrelated domains '*work processes, resourcing, scope/project initiation and tool mapping*'. Gu and London (2010, p988) noted: "*even market leaders who are early technology adopters … can have varying degrees of practical experiential knowledge of BIM … and different understandings and different levels of confidence regarding the future diffusion of BIM technology throughout the industry*". Literature has also focused on the impacts of external factors upon any implementation programme and various researchers (Succar, 2009; Succar *et al*., 2012; Wong *et al*., 2011) have provided reviews of publicly available international documentation including governmental policy, and guides, reports and standards provided by other institutes and organisations. The lack of strategic understanding demonstrated by project level practitioners harks back to the problems of information, communication and commitment addressed in earlier construction literature (Eastman *et al*., 2011; Johansen and Wilson, 2006; Vrijhoef *et al*., 2001) and highlights a wider problem related to the dissemination of any relevant academic research output to practitioners (Rynes *et al.*, 2001; Rynes, 2007).

This review of literature identifies several themes of note appropriate for exploratory research. A series of questions were generated that could be asked of construction project practitioners on an early adopter BIM project suitable for case study research. One such project was identified and questions that could be related to various aspects of Rogers innovation-decision process model were formulated. These questions focussed on:

- Perceptions related to BIM *(relates to Knowledge and Persuasion stages).*
- The identification of barriers to BIM implementation found within contracting organisations *(Persuasion stage).*
- Articulation of the benefits of BIM implementation and current use within contracting organisations *(Persuasion stage).*
- Key issues or problems that the use of BIM has helped solve in practice *(Implementation stage).*
- Pre-requisites needed within contracting organisations for the implementation and use of BIM.
- Impact of external factors upon organisational implementation programmes *(these two questions both relate to prior conditions which impact upon the innovation-decision process).*
- Personal observations and experiences of participation in an organisational BIM implementation programme *(Confirmation stage).*

Research methodology

A case study research strategy was adopted. Proverbs and Gameson (2008) described the use of case study research as being useful for the investigation of phenomena within a context. A case study approach was appropriate for purposes of exploratory research in order to investigate the progress of a BIM innovation implementation-decision by a large contracting organisation planning to adopt the use of BIM across all of their future projects. After familiarisation with appropriate initial literature, a suitable case was identified. Yin (2009) requires definition of the case itself and the unit of analysis to be made explicit when discussing components of case study research design. This case is a regional branch of a large international organisation, and the unit of analysis in this case relates to an aspect of organisational change - the process of BIM adoption by members within a subsection of the organisation. There is considered to be a *"dearth of research that investigates in qualitative detail processes of implementing innovations within construction"* (Harty, 2008 p1030) and this research provided opportunities to observe how the organisation and its staff adapted to a programme of organisational change, and can be classified as a revelatory case study. Evidence collected through this case study included recording of observations of the transition in progress, and qualitative data generated through in-depth semi-structured interviews with several project level employees. An interpretivist approach helped gain insight of employee perspectives regarding organisational BIM adoption. Emphasis was given to the subjects and themes drawn out using open-ended questions on general BIM awareness, and BIM use on the project. An iterative research strategy was used (Orton, 1997) where initial literature first informed the construction of the questions and post data collection thematic analysis afforded subsequent exploration of the literature.

Case Study

The case study organisation (CSO) operates in international markets and across the UK in the construction, property, design, facilities management, and services engineering markets, and is a near permanently fixture within the top 10 contractors as detailed in league tables associated with work winning, profit and turnover. The construction arm of the UK organisation provides new build and refurbishment solutions and operates in the following sectors: education; office; leisure; health; mixed development; and retail markets. The organisation has over 2,000 directly employed professionals and over the 2008-2013 six-year average, UK turnover was approximately £900M. The performance of the organisation closely followed general UK economic performance and the impact of the recession was thus: peak profits were reported in 2008 and peak turnover was reported in 2009 then a decline followed resulting in lowest profits in 2011, and lowest turnover in 2012 before recoveries began. CSO made the decision to roll out BIM across all of its operations shortly after the release of the 2011 Government Construction Strategy (GCS) and this research followed thereafter. The researcher was invited by a regional director to attend the organisations BIM user group meetings, where staff responsible for driving implementation at strategic and operational level across the region coordinated efforts. Issues discussed included company progress, BIM resistance at national and regional levels, and details of BIM partnerships with design consultants and their supply chain organisations. Increasing engagement with BIM innovation was observed during attendance at these meetings. One observation was of a strategic arrangement between the CSO and a leading software vendor that resulted in a 3 year, multi-million pound agreement enabling BIM to be embedded throughout their global operations, with technology used on every UK project regardless of size or scale. Archival records on the organisations BIM transition, including internal company documents such as BIM protocols; external documents including news items were reviewed. Increasing levels of research access was provided over the duration of the case study research allowing evidence to be gathered first through observation and documentation of two of CSO's first BIM projects – a leisure arena and a free school and finally via interviews.

Project A

When research commenced CSO was part way through the process of piloting BIM on a major high profile scheme, a £60m leisure arena project in England (Project A), and the researcher was invited to visit the project. Evidence collected including direct observations, field notes and data from unstructured discussions, although the researcher was unable to formally interview the participants at this stage. On Project A the organisation had utilised BIM to leverage many efficiencies and reported cost savings of £350,000 as a result of clash detection application, achieved a reduction in the production of 9000 drawing issues saved by using models, reduced onsite working time by 15,000 man hours and material wastage by 8%. Several major design issues had been resolved through the use of BIM and the researcher observed innovative practices by the design team using virtual meetings and web based modelling to achieve remote working, saving over 60,000 travel miles and helping the sustainability performance of the project. These efficiencies persuaded CSO of the value of BIM and reinforced the innovation adoption decision. The researcher was subsequently given further research access to the next BIM project (Project B) whereupon interviews were conducted with six members of CSO staff, a design manager, quantity surveyor, planner, IT manager and two separate construction managers (CM1 and CM2).

Project B

Project B was located in a de-industrialised town with a history of socio-economic deprivation. The project was a £8.98 million part new build construction of a free school to house 800 pupils. Several existing warehouse and transporting storage buildings had previously occupied the site and industrialised building solutions were implemented with framing elements from two existing structures being incorporated into the new build facility as solutions for sports and dining hall areas. Construction was of a fast track nature that incorporated two distinct phases of work to be handed over to the client. The first phase of work had a planned duration of 35 weeks, which included time for site clearance, demolition and new build with a further phase of 17-week new build period to follow.

CSO had previously completed several Building Schools for the Future (BSF) schemes and although Project A had created organisational experience of BIM, for many of the Project B site team this was their first exposure to the innovation. Procurement was design and build two-stage tender with several contractor design portion packages (CDP) required to complete the solution proposed by novated design team members. The design consisted of a simple steel frame with low-level masonry and cladding to upper levels. Roofing was a mix of standing seam and lightweight sarna materials. To achieve fast track construction and completion within budget, adoption of modular services equipment, reuse of existing building components and foundations and value engineering exercises were undertaken resulting in rationalisation to a fairly simple design. The coordinated model management for Project B can be seen in Figure 1. Important challenges included the adoption and use of BIM by the team within the rapid timeframe and use of a hybrid system of maintaining traditional project delivery processes whilst incorporating new BIM processes. Prominent themes that arose within the data analysis were the hybrid nature both of intra-organisation and inter-organisation BIM adoption within the wider Temporary Project Organisation (TPO), the quality of technological interoperability, and reliability of data generated.

INSERT FIGURE HERE

Figure 1: Project B – Coordinated model management [Photograph]

Process of interview content analysis

A Computer Assisted Qualitative Data Analysis Software (CAQDAS) package was utilised as a tool to aid the analysis of the qualitative data arising from these interviews (King, 2009; Yin, 2009). Audio from all interviews was captured digitally and then verbatim transcripts were produced. Interview transcripts were then formatted to meet the requirements of the CADQAS package and imported into the software application. Each section of the interview transcript content was then matched up with the relevant timings of the audio files to facilitate the ease of searching and retrieval of relevant sections of each interview. Codes were pre-assigned to capture and compare responses against each question and to subjects and themes identified in the initial review of literature with subsequent coding occurring during the analysis as various themes emerged.

Part of the interview required the interviewees to consider issues around organisational BIM adoption (benefits, barriers company pre-requisites, impacts of external factors) the remaining part of the interviews focused upon the specific use of BIM on Project B.

BIM: Preconceived perceptions, fears, concerns and hopes

Because BIM can be categorised as a radical disruptive innovation, first impressions were important. These were mostly positive, although participants variously reported initial limited perceptions over the information rich aspects that BIM affords and focused more on the improvements in 3D visualisation and in communicating spatial aspects of the physical product. It was reported that there had been a strong emphasis on the benefits of clash detection when BIM was first discussed within CSO. Several of the interviewees had experienced immersive aspects of non-intelligent 3D design on a previous project and had considered the application to be useful for purposes of communicating aspects of health and safety and future building maintenance. There was recognition that software would merely be an enabler, and that changes in culture and process would be required. The QS noted *"My first initial thoughts of BIM was that it would never work … it just seemed to be too much to expect from everyone … too many members, on too many teams … It's like a domino effect* [all it takes is] *one person who makes a mistake, then so does someone else … relying on people … it could get out of control … too many people inputting too many things"*

Barriers to the implementation of the use of BIM within contracting organisations

These were identified as challenges associated with existing culture and implementing change particularly amongst management members of staff who were perceived to be less

ICT capable. Interviewees generalised about the variance in technological capabilities being an issue between different age generations, rather than job roles with both indicating that in their experience younger members of staff had greater ICT abilities than the more senior generation. CM2 stated *"We've got a broad-spectrum of people here in terms of personality and age and drive within the business, you got the younger more technologically advanced side that are not frightened of technology and embrace it and then you have got an older, less … I was going to motivated but that's not the right word … less technologically understanding or capable generation … there needs to be willingness to understand it ... a willingness to get involved with the technology and get away from their own fears and embrace it … if people do that then very quickly you understand that it's really easy to use"*. Conversely it was identified that more junior staff may also not necessarily have the wealth of building knowledge that the senior staff have accumulated, and a two way transference of ICT and construction industry knowledge between these actors would be necessary. Returning to the theme of *willingness*, interviewees identified that more senior members of staff would expect to receive more structured ICT training where more junior members of staff would be more likely to adopt a more heuristic method of working with BIM. There was concern over the level of investment required, particularly for smaller supply chain contractors, and the perception of attitudes toward commercial risk and legal barriers from organisations who would be contractually engaged with CSO. In terms of technology, there was a large emphasis upon the implications of upgrading existing ICT infrastructure to accommodate resultant larger file sizes and the required increase in upload and downloads speeds, and the IT manager commented *"People just expect the infrastructure to be there"*. Commenting on aspects of inter company processes and current limitations of the technology, CM2 stated *"It's seen to be hard work because the technology is not where it needs to be, I* *think people have grand visions about what you can do, but the reality is that it doesn't do it just yet, and obviously there is the IFC* [technological interoperability] *issue, which doesn't help, and I think once we get through those barriers I can see real benefit in it, but I'm constantly struck by the fact that we can't do what we want it to do".*

Benefits to the implementation of the use of BIM within contracting organisations

Actual efficiency improvements being realised in practice were described. The QS reported upon time improvements during the process of undertaking the quantification of several structural foundation elements where direct exchanges of readable file types between the BIM applications used by CSO and the Structural design consultant had allowed this process to occur. Participants reported that they personally had gained greater understanding of the design, than in comparison to previous projects using only 2D non-intelligent design data. There were reported improvements in communication and understanding by the entre project team, and usage of the model to assist in the management of health and safety by capturing key visualisations where the delivery team had identified safety concerns in order to communicate these locations to site management staff.

It was confirmed that the use of clash detection technologies had been a key benefit actualised during construction. This was emphasised through several examples including the pre-installation resolution of clashes between main structural steel frame contractor and the roofing contractor, and at different interfaces involving the steel frame contractor and the curtain-walling contractor. The ease that resolution of these clashes were facilitated was discussed by CM1 *"I just take a snapshot* [from the model] *and send it to them and say 'we've got a problem here - we need to sort something out' … it's the classic phrase 'a* *picture says a 1000 words' - no one can argue when you send them picture that shows a steal beam running through a wall, it is obvious"*.

CSO used a range of different approaches to design coordination through clash detection functionality. The below exchange between the researcher [R] and the design manager [I] revealed use of the software that enabled automation of 'hard' rule based clashing of parametric objects in addition to a more necessary 'softer' approach of simple model navigation and interrogation necessary because of poor technological interoperability between files and platforms used on Project B:

1: *I'm finding things I wouldn't find ordinarily … with the architect, I've struggled a bit with clash detection, because of the way they build their models. I call it soft clash detection, the ability to make windows opaque and assign a different colour and realise there's a clash, not by* [an] *algorithm, but just by looking at them and realising that it doesn't look right, so for me it has been the soft clash detection that I've benefited from so far.*

R: *So hard clash detection is when it* [the application] *automatically does it?*

I: *Yes, there is an algorithm, so you take the steel model, take the cladding model and show where the clashes are.*

R: *So it automates it … soft clash detection is where you manually investigate it How would that have worked before in your role?*

1: *I'm not sure I would have found those things… [I] would have been sifting through lots of drawings, and asking - is that dimension correct? What about that one? But the reality is, we don't have time to do that.*

R: *If you didn't pick it up what would have happened?*

1: *The steelwork would have been in the wrong place, and we would be probably standing [no progress on site] for weeks waiting for steelwork to be moved so the curtain wall could go in.*

Key issues or problems that the use of BIM has solved or is helping to solve

CM2 provided a further example of the benefits of clash detection used to resolve logistical challenges associated with the transportation and positioning of major plant and equipment in a large-scale major industrial unit on Project C, which was in the pre-construction phase of the project delivery cycle, "*I have a factory layout of all the equipment that they* [client organisation] *are going to be bringing in, and they have given us 2D drawing information that we imported that into the model and it clashed with certain steelwork location positions within our model … so the box that they have been given to fit their equipment… included our columns inside of that boxed area. We already knew that there was a problem, so we looked at that and resolved it so we have already use clash detection for process fit out information. So they provided schematics or two-dimensional information, and then a Company BIM Coordinator remodelled this in a 3D environment to show the routes where the equipment would be delivered down to be installed into their final location*".

Perception of necessary pre-requisites within a contracting organisations for the implementation and use of BIM Models

Various responses focussed upon resourcing issues, with the QS addressing people issues: *"It's just culture, you need people who want to try and learn something different, with the correct attitude,* [and who understand the] *possible benefits … It's just about changing peoples attitudes, because there are a few people who don't really believe in it, but when you have explained what it could do and how you can save money with it has changed their opinion".*

CM2 focused on IT investment *"there is a realisation that [some] computers could not actually handle the software",* and identified that CSO had proactively upgraded much of the necessary ICT hardware including workstations and laptops to allow workers to yield the benefits of BIM outside of the usual cycle of planned ICT expenditure. Tool mapping was emphasised by interviewees in concerns that further expenditure was needed, with more software licenses being required than held, in order to allow staff who have processed the implementation message to be able to access the software and learn how to use the tools to perform the functions required.

Work processes were also considered by CM1 who first discussed the technological differences and preferences between generations: *"Construction as a whole has been a time served thing e.g. 'I've been in this industry for 30 years' - it's trying to get that man to embrace something that he's not used ever, and trying to get him to change - it's getting the man who if you put the model in front of him will still reach for the drawings it's getting him to change that kind of attitude".* This interviewee provided their perspective of the CSO BIM

Innovation implementation strategy *"They are moving in the right direction and it is developing like BIM itself, so embracing it within the company will be an on-going thing"*.

Impacts of external factors upon the implementation programme

Only two of the interviewees appeared to have any knowledge of the Government Construction Strategy (GCS) and the 2016 Level 2 mandate, and most responses indicated that these practitioners had little understanding of the 2011 GCS, with their knowledge of BIM coming only from the information provided by CSO. CM1 stated of BIM: *"It allows us to develop designs better and therefore help projects come on stream earlier, than historically may have happened, so BIM helps the designers value engineer better which then brings down the end price, helping a scheme that might not ordinarily have been approved"*. This participant further discussing the increased use of ICT within construction and continued *"I think … the economy has empowered people to move forward, because if you can show people you make a saving, everyone is going to jump on board, but I also think the industry as a whole was moving that way anyway, it was the next logical step, ICT has [now] come on board… it was only a question of when, but the economy has helped drive that a bit more … I also think the industry was going that way anyway"*.

Experiences of the implementation programme

Participants discussed aspects of organisational culture, provided insight into the differing attitudes of company workers toward the innovation, and considered the use of smaller monthly steering groups to facilitate implementation to be a positive approach. The design manager recognised that the direction and commitment of company leadership was proving effective in steering organisational change *"I wonder how much of it is organisational as well, I wonder if I was in a different organisation, that wasn't quite as savvy, would I still be pushing ahead to the extent the director has pushed me along - go off and use BIM on that job?"*

Discussion

The innovation decision process model developed by Rogers (2003) is applicable across the multiple levels (industry- organisation-project-individual) that decision-making units go through when considering adoption or rejection of BIM-innovation. In this case study, organisational-level, company leadership and knowledge were perceived as being effective in managing BIM innovation into use. At project-level variations in individual levels of use and adoption were apparent. CSO is an early adopter of BIM innovation, and analysis and observation reveals how such adopters will have to duplicate efforts and employ hybrid delivery methods. Several parallel processes are required to satisfy competing demands and preferences between ICT focused client and consultant transactions; inter-team preferences; and site level paper based needs in order to undertake project requirements. There were no contractual requirements imposed by the client team that required CSO to incorporate any BIM tools, or processes on this project, and at the preconstruction stage, the project largely proceeded in a traditional manner. CSO used these projects as learning opportunities whilst continuing to develop in-house BIM protocols in preparation for future projects. As identified by Gu and London (2010) there was evidence of varying intra-organisational use of BIM. Within the project team this ranged from: using it for entire job role (Design Manager); awareness of benefits but not using it, or believing that their role should be using it (Construction Project Manager); awareness of benefits and starting to use it to benefit job role

(Quantity Surveyor); to scepticism and not using it (Project Planner). This was despite a commitment from CSO that BIM would be used on all of its new projects. Individual beliefs and attitudes toward the consequences of BIM working in a TPO align with previous studies (Brewer and Gajendran, 2012; Davies and Harty, 2013b; Jacobsson and Linderoth, 2010) particularly over the immediacies of project deadlines, culture, compatibility with working process and preferences, and technological acceptance. One anticipated organisational challenge would be the deployment of human resources between technologically adverse and technologically accepting persons. These attitudes have been attributed in literature to generational differences between *digital immigrants* and *digital natives* (Prensky, 2001a; 2001b) and were observed first-hand by the researcher and reflected upon by several participants.

On Project B, the design process was managed via rolling two weekly uploads and reviews of consultant team models. Interviewees noted concerns over the hybrid nature of these processes on this project that centred not just inter-organisational BIM use, also on transactions with wider TPO partners. The hybrid construction project production information processes for project B can be seen in Figure 2. Variation in levels of BIM engagement within the information management processes of the consultant team partners was observed. Models were issued by the novated project Architectural team and by the Structural Engineers who both worked with BIM methodology, but not by the MEP consultant or subcontractors with design responsibilities who continued to issue only 2D production information. The inner workings of this project appear to provide further evidence confirming findings from previous innovation diffusion literature, i.e. because of difficulties crossing multiple organisational boundaries in a TPO and the separation of projects into distinct stages, construction projects are subject to a slower rate of innovation diffusion (Gambatese and Hallowell, 2011; Harty, 2008; Taylor and Levitt, 2004).

INSERT FIGURE 2 HERE

Figure 2: Hybrid construction project production information processes employed by CSO on Project B

One of the biggest challenges facing the diffusion and adoption of BIM innovation is how the innovation should be implemented. More recent research (Arayici *et al.*, 2011; Davies and Harty 2013a) argue that implementation should driven from project-based employees which is analogous to the emergent approach to change within organisational change literature, rather than through top down control (aka the planned approach to change) by corporate management as evidenced in the CSO. These perspectives differ from an earlier model of construction innovation processes developed by Winch (1998) which states that the two dimensions of top down adoption/implementation and bottom-up problem solving/learning approaches are equally as important in the construction innovation process.

The researcher observed that coordination between CSO and the consultant team was largely via issue of models, whereas production information was used to engage in client interaction and communication at project meetings was performed solely using 2D drawings, likewise all in-house contractor team meetings still revolved around 2D information when discussing issues or problem solving, raising concerns over communication effectiveness. At tender stage, despite the availability of 3D models, all subcontractors were issued 2D information for purposes of tendering and building. CSO reported that site managers were getting familiar with seeing design information in 3D via specially created viewpoints on the model for areas involving increased safety risks or complex build sequences, but also continued to use drawings on site. Post project discussions with the project team revealed that the project was viewed as a missed opportunity from the perspective of engaging key subcontractors including MEP, Cladding and Structural Steel trades to use the model for production aspects such as cutting schedules. Caution was voiced by the QS discussing advances afforded by BIM: *"it's improving the process, but it's reducing communication"*. Clash detection operations were considered to have been successful on this project – particularly use of '*soft clash detection*', although there was an awareness that despite this technique, several clashes had still been missed, also the level of investment remained a concern with a residual belief amongst the staff that training required investment of £10,000 per seat. The TPO experienced noteworthy ICT challenges, particularly issues associated with technological interoperability. A primary concern was the exporting and importing capabilities of perceived incompatible cross vendor Design Authoring Software and Model Review and Management Software even when making use of industry advocated IFC files.

Practical and theoretical implications

For organisations considering their response to BIM an interesting parallel can be drawn with a similar programme of innovation-adoption that occurred in the late 1990's when greater use of IT supported collaborative construction project management (CCPM) web based project management tools were introduced. The legacy of these tools are that initial hybrid delivery processes adopted by construction organisations never led to optimised information management systems and still remain in widespread use. Web-hosted electronic systems are currently used for communication and information transactions with client, consultant and major subcontractor teams, whilst concurrent paper or email-based systems are also used to issue production information to other subcontract organisations. These hybrid systems are inefficient, duplicate effort and reduce available time, and mismanagement can create costly errors in the construction process. These research findings raise concerns that without careful consideration similar hybrid delivery processes for BIM enabled projects could become normalised across the industry, and these inefficiencies will continue.

There are several implications for research. From a technological perspective, the findings indicate a need for more focussed research efforts into areas of interoperability in order to assist practitioners realise better results in their design review and coordination processes. From sociological and process oriented perspectives, further case study research efforts are needed in order to assess BIM-innovation diffusion within temporary project organisations and across construction organisations. Questions that could be considered by researchers relate to aspects of design management and information review processes, such as: In order to manage construction information through to approved production status, how does the status of all data within a model relate to design output produced using traditional production information processes? Should individual BIM objects generated via an object oriented design approach obtain individual design approvals, separate from the status of the entire model? And which mediums take precedence in instances where traditional and model based design information appear to contradict each other?

Conclusion

In this research, the impact of BIM innovation adoption upon the project delivery processes of a single organisation was studied during the implementation stage of the innovation decision process. This was done because BIM has been classified as a disruptive innovation (Poirier *et al*., 2015) with the potential to change how construction projects are delivered (Loosemore, 2014; Succar, 2009). Case study research was undertaken and several benefits were reported by research participants, however it was also observed that the management of production information processes on BIM enabled projects required duplication in effort that could contribute to error creation in the delivery process. It is predicted that early adopters of BIM innovation may need to initially employ hybrid delivery methods on early BIM enabled projects, and efforts to optimise such systems are recommended.

The use of a single case study organisation was a research limitation and there can be obvious criticisms made about such research design. However, despite the uniqueness of each construction project, the approach taken on this case study is replicable. To undertake related study, access would be required from organisations that have taken a similar top-down *Authority Innovation-Decision*. Depending upon the maturity of the BIM innovation research field at such a time, these studies could then be considered representative cases. Causality (internal validity) was not a focus of the design of this research, however the results have a degree of external validity as they can be generalised beyond the individual project context. BIM innovation diffusion at particular levels within industry, such as across comparable organisations appears to align with the general innovation-diffusion process popularised by Rogers (2003). Claims over external validity at industry and individual practitioner levels cannot be made due to structural complexity and technology acceptance issues addressed elsewhere in the literature. There is still a need to considering BIM innovation-diffusion from all aspects of the process-technology-sociological perspectives, and more case studies of BIM use are required in order to further understand consequences of organisational BIM innovation adoption/rejection decisions made.

References

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. (2011), "Technology adoption in the BIM implementation for lean architectural practice", *Automation in Construction*, Vol. 20 No.2, pp. 189–195.

Barlish, K. and Sullivan, K. (2012), "How to measure the benefits of BIM — A case study approach", *Automation in Construction*, Vol 24, pp. 49–159.

Bryman, A. (2012), Social Research Methods 4th Edition, Oxford University Press, Oxford.

BIM Industry Working Group. (2011), A report for the Government Construction Client Group, *Building Information Modelling (BIM) Working Party Strategy Paper*, London

Bew, M. and Underwood, J. (2010), "Delivering BIM to the UK Market", in *Handbook of Research on Building Information Modelling and Construction Informatics Concepts and Technologies*. IGI-Global, pp. 30-64

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*, Vol 12 No. 2, pp. 198–215.

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

Davies, R and Harty, Chris (2013a), "Implementing 'Site BIM': A case study of ICT innovation on a large hospital project" *Automation in Construction*, Vol 30, pp. 15-24.

Davies, R. and Harty, C. (2013b), “Measurement and exploration of individual beliefs about the consequences of building information modelling use”, *Construction Management and Economics*, Vol. 31 No.11, pp. 1110-1127.

Dubois, A., & Gadde, L. (2002). “The construction industry as a loosely coupled system: implications for productivity and innovation”, *Construction Management and Economics*, Vol. 20, No. 7, pp. 621–31.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011), BIM handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, 2nd Edition. John Wiley & Sons, Inc, Hoboken, NJ

Gambatese, J. and Hallowell, M. (2011), “Enabling and measuring innovation in the construction industry”, *Construction Management and Economics*, Vol. 29 No. 6, pp. 553–567.

Gann, D. and Salter, A. (2000), “Innovation in project-based, service-enhanced firms: the construction of complex products and systems”, *Research Policy*, Vol. 29, No. 7-8, pp. 955–972.

Grilo, A and Jardim-Goncalves, R. (2010), 'Value proposition on interoperability of BIM and collaborative working environments', *Automation in Construction*, Vol. 19, No. 5, pp. 522-530

Gu, N. and London, K. (2010), “Understanding and facilitating BIM adoption in the AEC industry”, *Automation in Construction*, Vol. 19 No. 8 pp. 988–999.

Harty, C (2008), “Implementing innovation in construction: contexts, relative boundedness and actor‐ network theory”, *Construction Management and Economics*, Vol. 26 No. 10, pp. 1029–1041.

HM Government. (2011), Government Construction Strategy, Cabinet Office, London

Hosseini, M. R., Chileshe, N., Zuo, J., and Baroudi, B. (2015), “Adopting global virtual engineering teams in AEC Projects: A qualitative meta-analysis of innovation diffusion studies”, *Construction Innovation: Information, Process, Management*, Vol. 15, No. 2 pp. 151–179.

Huang, T., Li, H., Guo, H., Chan, N., Kong, S., Chan, G. and Skitmore, M. (2009), “Construction virtual prototyping: a survey of use”, *Construction Innovation: Information, Process, Management*, Vol. 9 No. 4, pp. 420–433.

Issa, R. and Suermann, P. (2009), “Evaluating industry perceptions of building information modeling (BIM) impact on construction”, *Journal of Information Technology in Construction (ITcon)*, Vol. 14, pp. 574–594.

Jacobsson, M. and Linderoth, H. C. J. (2010), “The influence of contextual elements, actors’ frames of reference, and technology on the adoption and use of ICT in construction projects: a Swedish case study”. *Construction Management and Economics*, Vol. 28 No. 1, pp. 13–23.

Johansen, D.E and Wilson, B. (2006), “Investigating first planning in construction”, *Construction Management and Economics*, Vol. 24 No. 12, pp. 1305–1314.

Kanter, R. M., Stein. B. and Jick. T. (2001) Challenge of organisational change: How companies experience it and leaders guide it. Simon and Schuster, New York.

Kassem, M., Iqbal, N., Kelly, G., Lockley, S., and Dawood, N. (2014). Building information modelling : collaborative design processes protocols. Journal of Information Technology in Construction, 19(July), 126–149.

King, A. (2008), “Using software to analyse qualitative data”. In: Knight, A. and Ruddock, L (Eds). *Advanced Research Methods in the Built Environment*. Wiley-Blackwell, Oxford, pp. 135–141.

Kotter, J. (2012). Leading change (New ed.). Boston: Harvard Business Review, Boston, Massachusetts

Li, H. (2012) “The use of virtual prototyping to rehearse the sequence of construction work involving mobile cranes”. *Construction Innovation: Information, Process, Management*, Vol. 12, No. 4, pp. 429–446.

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*, Vol. 27 No. 4, pp. 363–371.

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

Luecke, R. (2003). Managing change and transition (Vol. 3). Harvard Business Press, Boston, Massachusetts

Mäki, T. and Kerosuo, H. (2015) “Site managers’ daily work and the uses of building information modelling in construction site management”, *Construction Management and Economics*, Vol. 33, No. 3 pp.163-175.

Orton, J. D. (1997), “From inductive to iterative grounded theory: Zipping the gap between process theory and process data”. *Scandinavian Journal of Management*, Vol. 13 No. 4, pp. 419-438.

Owen, R., Amor, R., Palmer, M., Dickinson, J., Tatum, C., Kazi, A., Prins, M., Kiviniemi, A. and East, B. (2010), “Challenges for Integrated Design and Delivery Solutions”, *Architectural Engineering and Design Management*, Vol. 6, No. 4, pp. 232–240.

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*, Vol. 15, No. 1, pp.42-65

Prensky, M. (2001a), “Digital Natives, Digital Immigrants Part 1”, *On the Horizon*, Vol. 9, No. 5 pp. 1-6.

Prensky, M. (2001b), “Digital Natives, Digital Immigrants Part 2: Do They Really Think Differently?”, *On the Horizon*, Vol. 9, No. 6 pp. 1-6.

Proverbs, D. and Gameson, R. (2008) Case study research. In: Knight, A. and Ruddock, L (Eds). *Advanced research methods in the built environment*. Wiley-Blackwell, Oxford, pp. 99–110.

Rekola, M., Kojima, J. and Mäkeläinen, T. (2010), “Towards Integrated Design and Delivery Solutions: Pinpointed Challenges of Process Change”, *Architectural Engineering and Design Management*, Vol. 6, No. 4 pp. 264–278.

Rogers, E. M. (2003). Diffusion of Innovations 5th Edition, Free Press, Simon & Schuster, New York, N.Y.

Rwamamara, R., Norberg, H., Olofsson, T. and Lagerqvist, O. (2010) “Using visualization technologies for design and planning of a healthy construction workplace”, *Construction Innovation: Information, Process, Management*, Vol. 10, No. 3 pp. 248–266.

Rynes, S. L., Bartunek, J. M., and Daft, R. L. (2001), “Across the great divide: Knowledge creation and transfer between practitioners and academics”, *Academy of Management Journal*, Vol. 44, No. 2 pp. 340-355.

Rynes, S.L. (2007). “Editor’s Afterword - Let's Create A Tipping Point: What Academics and Practitioners can do, Alone and Together”, *Academy of Management Journal*, Vol. 50, No. 5 pp. 1046–1054.

Sacks, R., Koskela, L., Dave, B. and Owen, R. (2010), “The interaction of lean and building information modeling in construction”, *Journal of Construction Engineering and Management*, Vol. 134, No. 5 pp. 968-980

Sebastian, R. (2011), “Changing roles of the clients, architects and contractors through BIM”, *Engineering, Construction and Architectural Management*, Vol. 18, No. 2 pp. 176-187.

Senior, B. and Swailes, S. (2010) Organizational change, 4th Ed Financial Times/Prentice Hall, New York.

Slaughter, E. (2000), "Implementation of construction innovations", *Building Research and Information*, Vol. 28, No. 1 pp. 2–17.

Stapleton, K., Gledson, B. J., and Alwan, Z. (2014). "Understanding technological interoperability through observations of data leakage in Building Information Modelling (BIM) based transactions". In E. Thompson (Ed.), Proceedings of the 32nd eCAADe Conference (Vol. 52, pp. 515–524). Newcastle Upon Tyne, England, UK, 10-12 September 2014: eCAADe.

Succar, B. (2009), "Building information modelling framework: A research and delivery foundation for industry stakeholders", *Automation in Construction*, Vol. 18, No. 3 pp. 357–375.

Succar, B., Sher, W. and Williams, T. (2012), "Measuring BIM performance: Five metrics", *Architectural Engineering and Design Management*, Vol. 8, No. 2 pp. 120–142.

Sulankivi, K., Makela, T. and Kiviniemi, M. (2009), "BIM-based site layout and safety planning". In *1st International Conference on Improving Construction and Use through Integrated Design Solutions CIB IDS 2009*, *Technical Research Center of Finland*, pp. 125-140

Taylor, J., and Levitt, R. (2004), "A new model for systemic innovation diffusion in project-based industries", *CIFE Working Paper WP086*, *Project Management Institute International Research Conference.*

Todnem, R. (2005), "Organisational change management: A critical review", *Journal of Change Management*, 5(4), pp. 369–380.

Vrijhoef, R., Koskela, L. and Howell, G. (2001), "Understanding construction supply chains: an alternative interpretation", In *Proceedings 9th Annual Conference International Group for Lean Construction*, pp. 185-199

Winch, G. (1998), “Zephyrs of creative destruction: understanding the management of innovation in construction”, *Building Research & Information*, Vol. 26, No. 5 pp. 268–79.

Wong, A.K.D.D., Wong, F.K.W. and Nadeem, A. (2011), “Government roles in implementing Building Information Modelling systems: Comparison between Hong Kong and the United States”, *Construction Innovation: Information, Process, Management*, Vol. 11, No. 1 pp. 61–76.

Yin, R. K. (2009) Case study research: design and methods, 4th Edition, Sage Publications, Thousand Oaks, California.