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# Implementing 'Site BIM': A case study of ICT innovation on a large hospital project

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ABSTRACT

Numerous Building Information Modelling (BIM) tools are well established and potentially beneficial in certain uses. However, issues of adoption and implementation persist, particularly for on-site use of BIM tools in the construction phase. We describe an empirical case-study of the implementation of an innovative 'Site BIM' system on a major hospital construction project. The main contractor on the project developed BIM-enabled tools to allow site workers using mobile tablet personal computers to access design information and to capture work quality and progress data on-site. Accounts show that 'Site BIM', while judged to be successful and actively supporting users, was delivered through an exploratory and emergent development process of informal prototyping. Technical IT skills were adopted into the construction project through personal relationships and arrangements rather than formal processes. Implementation was driven by construction project employees rather than controlled centrally by the corporate IT function.

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## 1. Introduction

Many aspects of construction suggest the significant benefits that the industry could derive from information and digital technologies: the huge amounts of information to be managed; the emphasis on production; and the dispersal of participants. Despite this, IT adoption is generally thought to be limited and predictions of future adoption have proved to be optimistic [1]. Although more enthusiastic champions have been disappointed, the use of digital technology has increased in construction. One important digital technology is Building Information Modelling (BIM) — a means of representing and analysing building designs as three-dimensional assemblies of objects with multiple data attributes. Elements of BIM such as: 3D representation; computer-aided design; automatic clash detection for design coordination; and various forms of electronic communication are widely used in design projects [2].

However, site management work is still dominated by paper whether in the form of drawings and other design information or in the use of paper notes and forms for capturing information. Proponents of increased use of digital technologies on-site point out the costs, errors and delays associated with translating paper-based data to digital and vice-versa as information flows from site to office and back [3]. Research has largely concerned itself with design work in the office environment. As Sacks et al. put it, "with few notable exceptions, most of the academic and industrial research…deals with design and with pre-construction planning. There has been far less effort to develop BIM based tools to support coherent production management on site" [4]. This paper is part of a research project that seeks to contribute to that effort. Our research is a case-study of a real-world project to implement BIM-related tools and Tablet Personal Computers for mobile computing use on-site during the construction phase — 'Site BIM'.

This paper is organised into a number of sections. It begins with a brief review into Site BIM and mobile computing and into innovation in construction followed by an account of our research methods. Our findings are presented in two parts; a non-technical description of the Site BIM technologies implemented and then a detailed description of the implementation effort itself drawing on interviews with the people responsible. Finally, our general discussion draws out a number of themes and discusses them in terms of the construction innovation literature and implications for practitioners and researchers in this area.

### 1.1. 'Site BIM' and mobile computing

Building Information Modelling (BIM) in its most basic form is a combination of CAD, database and graphical technologies that allow users to design and represent buildings and their components in terms of an assembly of inter-connected objects in a coordinated, scaled 3D model. More broadly, the term "BIM" has come to mean a wide range of related digital technologies and associated business processes used for representing and managing information throughout project and facility life cycles. The representation of building elements as objects in a database allows for further information to be associated with each instance of an object in the building model.

There is apparent consensus that BIM technology is proven and that the design management benefits are clearly established and widely used [2]. Recent industry surveys suggest adoption figures as high as 64% for responding designers [5]. This relative success of the

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use of BIM for design appears to have encouraged the possibilities of the technologies to automate and improve the construction process by joining up the design, construction and handover processes, re-using the same information down the supply chain and digitally mediating construction activities. Participants in our research prefer to talk about building information *management*, of which modelling is only one part — so-called "Big BIM", "The focus is on managing projects to get the right information to the right place at the right time" [6].

In construction, getting the right information to the right place means overcoming the challenges of the organisational fragmentation of the industry and the site-based location of much of its work. The benefits of using tools such as BIM and 3D visualisation to communicate design intent are limited when the final stage of delivery of the information to the work site is dominated by paper drawings and information and limited to 2D representation [4]. In order to overcome this, various forms of personal computer systems have been trialled and implemented on construction sites since the early 1990s including electronic pocketbooks, laptop PCs and personal digital assistants (PDA) (see Kimoto et al. [3] for a review). Other examples include: delivery of steel fabrication drawings to PDAs [7]; delivering information to site via 'information booths' [8]; and large on-site touch screens [4].

As well as delivering digital design data to site, a number of organisations and researchers have developed systems to use and capture site-generated data to support the construction process. Kimoto et al. [3] describe a PDA-based software system including components for site managers to perform inspections, position checks and progress monitoring. The information on the PDA memory card is then uploaded to office PCs for collation and analysis. Kim et al. [9] implemented a similar wireless-networked system for quality inspections and defect management also using PDAs. A step further towards automation can be seen in trials of 3D scanning and photogrammetry to detect installed building components [10].

### *1.2. Research in construction innovation and the adoption of digital technologies*

The previous examples of construction-specific digital technologies, along with the variety of commercial products available and the level of adoption in other industries, all support the view that the technology innovation challenges for construction are institutional and organisational in nature. In the construction management literature, studies of technology development and adoption have drawn heavily on the domain of innovation studies [11]. Much of the construction innovation research has been interested in innovation itself as the focus of study drawing on examples of innovation to develop general insights into innovation [12]. A common starting point for such research is the low rate of construction innovation compared to other industries and consequent failure to improve productivity and quality [13]. This has lead to attempts to understand the nature of the industry particularly as it relates to firms' willingness and ability to develop and adopt innovations. Central to this attempt are analyses of the implications of the dominant forms of organisation in the industry and its project-based mode of delivery.

Innovation researchers understand construction as a 'complex systems industry' [14]. For each construction project, a diverse group of actors and organisations (contractors, designers, suppliers, clients, regulators etc.) has to be brought together in a network for the delivery of a particular project. In Winch's [14] model, principal contractors and designers act as joint 'systems integrators' that bring together and coordinate the elements of the network. In terms of innovation, this network creates multiple sources of innovations both top-down from the 'innovation superstructure' (clients, regulators, professional institutions) and bottom-up from an 'innovation infrastructure' composed of; trade contractors, specialist consultants and component suppliers.

The other significant feature of the construction industry necessary for understanding construction innovation is the project-based mode of delivery. Significant amounts of the industries' work are delivered on and through projects which are usually geographically separate from the firm's permanent office. Temporary project organisations also make up a large percentage of the overall construction organisation. The distinction between project and firms is important as "innovations in construction are, typically, not implemented within the firm itself, but on the projects upon which the firm is engaged" [14]. Winch outlines two main innovation processes: firms *adopt* innovations and *implement* them on projects; and projects *solve problems* and firm *learn* the solutions. Gann and Salter [15] also emphasise the role of projects in construction innovation outlining the importance of realising that firms are not single, definable entities and that in project-based firms in particular, project teams may have little contact with the firm's senior management and tenuous links to the central core of the firm. It is implicit in Gann and Salter's research that project teams are thought of as needing technical support and services from the firm and that the firms' central departments are seen as both supporting projects and capturing learning on projects. However it is acknowledged that "project teams are involved in a considerable amount of 'practitioner-research' and they often develop expertise in the course of their project activities" [15].

The research in construction innovation tells us that understanding the processes by which new digital technologies are implemented, adopted and diffused, requires our analysis to consider the networked and project-based nature of the industry. Recent in-depth case-studies of ICT innovation in construction have shown that the way ICT implementations unfold can be strongly influenced both by the emerging dynamics within the innovation project and the social and organisational context in which it operates [16,17]. The aim of our research is to describe and understand how new digital technologies are implemented in construction projects. Descriptions of implemented systems are important in communicating what is possible. Equally important is to understand how such technologies are, and could be, implemented in the construction context. Construction is not unique in all respects — for example, the conclusions that construction firms, rather than projects, have the instigating and supervising role with respect to innovation processes is reflected in mainstream project management research [18]. This literature tends to view projects as subordinate to the parent organisation [19]. However, the analysis of challenges to technology adoption in previous research has shown the salience of distinct features of the industry's work and organisation. This paper draws on case study research to discuss one contractor's approach to developing a 'Site BIM' system to support construction operations. In the following sections we describe the research methods, the site BIM system (portable tablet computers and software and data elements), the reasons for the innovation, the development methods used and the relationship between the innovating project and the parent firm.

## 2. Research methods

### *2.1. Case study details and research design*

Our research follows a leading, real-world project to develop and implement BIM technologies for use in the design, construction and operation of a large United Kingdom hospital. 'Hospital Project' is a combination of new build, demolition and refurbishment work across two large city-centre hospitals and one of the largest such projects in Europe with a contemporary value of over £1 billion. At the time the interviews were conducted, design was complete and construction well progressed with phases of the work being handed over for commissioning. Final completion of the construction work is scheduled to be fully completed in 2016. The project was funded through a public–private partnership deal and contracted on a design-and-build basis with a multi-national contractor ('Contractor') leading the project team. The contractor also has responsibility for the facilities management of the project for thirty years after handover.

The research design is an on-going longitudinal case study undertaken in phases of retrospective data collection. Our approach is to focus on drawing lessons from specific cases as advocated by Flyvbjerg [20]. Case study research has been criticised as 'unscientific' for not supporting formal generalisation and being prone to bias and verification. Flyvbjerg strongly defends case studies, arguing that formal generalisation is overvalued compared to the 'force of example'. Also, generalisation from case-study is possible — for example in providing a counter-example to widely held findings or beliefs. Further, the complexity of real-world cases tends against confirmation bias as the complexity and internally contradictory nature of organisational life are likely to challenge simple preconceptions. This approach is reflected in, "a growing interest among several [digital construction] research communities in the experiences gained from applying new technologies to practice" [21] and with Harty's [16] call for more studies of the process and context of implementing innovations on construction projects. The research described in this paper focuses on the development of tools for use during the construction phase and on the construction site.

### 2.2. Data collection and analysis

Our data includes: formal, transcribed, semi-structured interviews; documents; informal meetings and discussions; observations; and feedback on reports. The formal interviews were conducted with fifteen of the main contractor's project staff responsible for oversight, implementation and use of BIM on the project (two Design Directors, Project Manager, Operations Manager, two Document Managers, two Quantity Surveyors, two Compliance Managers, BIM Co-ordinator, Design and Compliance Manager, Environmental Manager, Project Information Manager, BIM and 3D CAD Manager.) The interviews followed a schedule (participant information; use and experience with BIM tools on the project; role within the IT implementation project; benefits and challenges; changes to communication and construction practices; future developments) but participants were allowed freedom to discuss their experiences and thoughts about BIM in their own terms. The initial research question was to learn about 'BIM' in the construction phase and on the construction site and site offices. Our participants told us about: the BIM systems on the project (see Section 3); the salient features of construction work on Hospital Project and the problems that the BIM systems were intended to address (see Section 4.1); and accounts of the implementation of the BIM systems (See Sections 4.2–4.4). Our initial analysis of the data was to produce a descriptive account based on our participants' own words with limited reference to ICT or innovation research concepts. For example, the emphasis on tablet computers in the account reflects the importance attached to this aspect of the technology on the project by our participants rather than any prior assumption about the role of artefacts in innovation processes. Subsequent analysis of this account in terms of the literature identified general findings with implications for construction ICT implementations and the relevant literature (Sections 5.1–5.3).

## 3. 'Site BIM' systems

The 'Site BIM' systems implemented on the project, and their organisation, are shown in Fig. 1. Although technically distinct, and sometimes distinct in use, these components together are described as those making up 'BIM' on the project. As such they are all interconnected both in system terms and also in the understanding of project actors. The following sections describe each of these elements in more detail.

### 3.1. Tablet computers

For impact on on-site construction activities possibly the most significant, and certainly the most visible component was the purchase of portable tablet computers. The tablets not only provided the vehicle for making use of underlying BIM model data but also acted as a functional capability that placed opportunities, demands and expectations on the underlying IT systems. The tablets are fully functioning networked personal computers with the standard Contractor corporate build (Microsoft Office, corporate email etc.) as well as the additional BIM systems developed for and implemented by the project. Tablets are operated via stylus as gloved hands and bulky cuffs were found to cause issues for touch-screen interfaces (see Fig. 2). For site use they operate in a stand-alone 'briefcased' mode. Project BIM data is synchronised when the tablet is connected to project office corporate network.

### 3.2. Coordinated 3D BIM models

Coordinated 3D BIM models were produced during the design phase of Hospital Project. Technically, the BIM models are standalone copies of model files located on site office servers, maintained and co-ordinated by Contractor Document Controllers. They are available to networked PC users and, through a synchronisation process, on tablet PCs for site users. Due to capacity limitations they are split into floors and/or zones for each building. The BIM models were used during the design phase to help achieve a co-ordinated design through automated clash-detection and design meetings in which the models were projected on large screens. Once the design was fixed and project 'financial close' was achieved, they were not updated — small subsequent design changes were made to CAD drawings directly. As such the models are effectively a read-only element in these systems. They also function as the reference/navigation data for the new 'Site BIM' functionality developed on the project.

### 3.3. DMS (Document Management System)

DMS is Contractor's in-house developed and maintained project document management system. It is accessible to designers and contractors over the internet to upload and receive information. The information distribution element of DMS is manually operated by Contractor Document Controllers. Drawings are explicitly issued (emailing a clickable fixed link to a specific version of a specific drawing) by Document Controllers using DMS. As an application DMS is an open platform. Projects can develop their own structure, document types and metadata. This means that all projects can, and do, set up DMS differently and on Hospital Project went through a phase of being *"a bit of a shambles"* with respect to meta-data setup and file structure. It is also considered difficult to search for documents via its complex 'administrator/super user' interface.

### 3.4. Site dBase

Site dBase is an externally produced software product purchased by the Hospital Project. It consists of a 3D BIM model viewer and database functionality to allow attribute metadata (including document links) to be associated with objects in the model and to use these relationships for display, searching and reporting. Site dBase also effectively does the job of integrating other data elements. The 3D model viewer packaged with Site dBase is also used as a standalone application by site office PC users. It allows navigation through the model. A DMS link from Site dBase presents latest drawings or other documents as a pdf or dwf (see Fig. 3). The ability to link from Site dBase to DMS was developed as part of the BIM innovation project.

Further new development of Site dBase was undertaken to develop 'Progress', 'Compliance' and 'Defects' functionality. These are pieces of

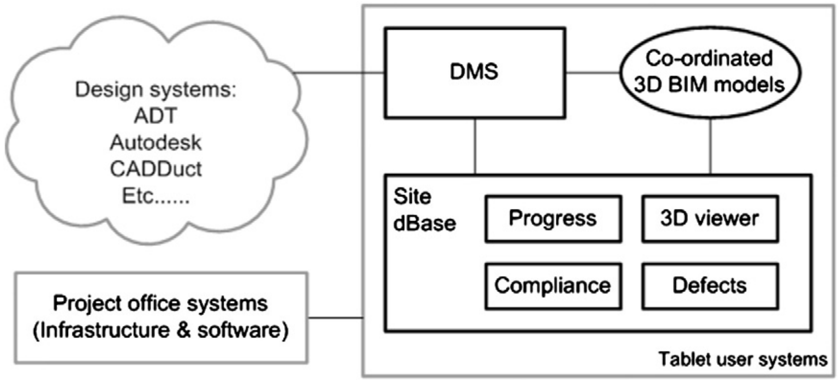


**Fig. 1.** Hospital Project Site BIM systems.

discrete functionality implemented as bespoke Site dBase tables and forms to capture user-generated data and associate it with objects in the 3D models. Each of the elements allows a user with a tablet PC inspecting for progress, compliance or defects to select a building object via the 3D floor-plan generated from the BIM and complete a form to enter the data (see Fig. 4).

For progress checking, this form is a list of around eighty interdependent activities per room and a smaller number for each wall section. For compliance checking, the form is a compliance checklist generated from the room data sheet (a textual design document listing the fixtures, fittings and equipment installed in each room). The defects function is very similar to the compliance checklists although more complex as any object (room, partition) can have any number of defects created by the user. Alongside each item is the ability to select a status for each element as well as associated comments. Additional development was done to use the progress data to automatically generate 'marked-up' coloured general arrangement drawings showing progress to use in coordination meetings.

**Fig. 2.** Use of tablet PCs during Hospital Project fit-out.

### *3.5. Project office systems*

In addition to the specific 'BIM' elements adopted or developed by the project, a number of other systems are necessary to support the site BIM system. These were mentioned but not emphasised by our participants, being so well established as to be thought of as the context for the BIM innovations rather than part of them. One class of related elements are the design tools and systems that were used for the design of the buildings and the creation of the 3D BIM models. This digital design environment is not the focus of this paper and so is represented in Fig. 1 as an external source of drawings and other documents passed through the project DMS. The final element in Fig. 1, project office systems, is a catch-all for the additional hardware and software systems necessary for the 'tablet user systems' to function. These include application and data servers, network infrastructure, operating systems and so on. Also included here are generic software components such as email (necessary for DMS distribution functions) and spreadsheet software (to process data extracted from the BIM via Site dBase to perform analyses such as materials take-off, or waste measurement).

## 4. The 'Site BIM' implementation

The remaining sections of the paper present both a description of the Site BIM implementation process and an analysis of the salient themes identified from participants' accounts. In this section the emphasis is on description of the implementation organised into the following categories: reasons for adoption; a history of the rollout; a description of the implementation approach and practices (including the actors involved); and finally a discussion of the relationship between Hospital Project BIM team and the corporate IT department. The next section is a discussion of three general themes in the data and their relationship to the literature; notions of the success of the innovation; the emergent quality of the BIM technology and practices; and the importance attributed to its project-led nature.

### *4.1. Reasons for adoption*

The reasons given for the adoption of tablet PCs and related BIM systems on Hospital Project fall into two broad categories: a general concept of the problems of design and construction and the appropriate response; and specific features of Hospital Project.

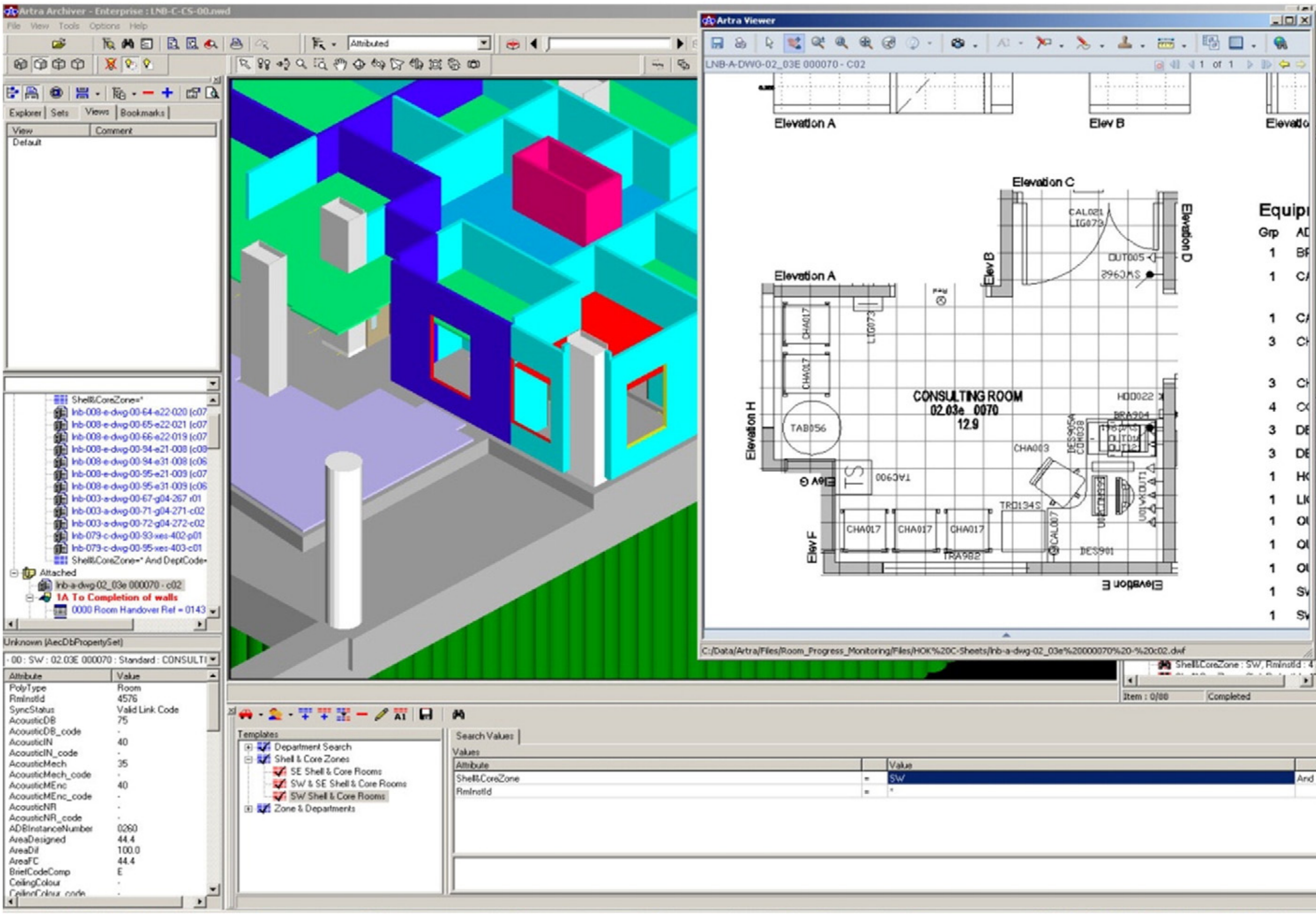


**Fig. 3.** Using 3D viewer and Site dBase to access design drawings for consulting room.

From the more general perspective, the implementation of BIM systems implicitly adopted a phased sequential view of the construction process in which the use of BIM during the design phase is intended to support the development of a correct and therefore fixable 'final design'. Technology then allows this to be presented to construction teams for error-free implementation and captures site data that ensures and confirms compliance with the design. A number of the Site dBase developments described here are explicitly designed to both ease and manage the way people work, "*So what we're forcing the Construction Managers to do is to actually go down the road of actually double checking and job checking everything they're doing*". And the systems and associated procedures also appear to have been implemented in the expectation of the risk of deviation in their use. "*It's controlling them to do their job because it's got to be done in a certain mode. It can't be done any other way, i.e. it's either yes or no in terms of room compliance*".

The specific features of Hospital Project that were used to justify the Tablet PC systems development were the scale and speed of the project and the construction management approach used. (Additionally, the complexity of the design had been an important reason for the use of BIM for design-phase coordination). One issue in the latest stage of the project is the scale of the works and the effort required to manage their construction. Hospital Project has a programme of handing over 6500 rooms to the client. Each handover requires a number of processes including progress monitoring, snagging (faults and damage), compliance (correct equipment installed correctly as confirmed by the client's Independent Tester) and certification. *"You know everyone's got important deadlines to achieve. I mean at the moment, we're trying to do fifty rooms a week to be finished and locked out and that goal is until July of next year"*. This volume of work provided the business case for the partial computerisation of the checking and handover process using Tablet PCs and the Site dBase developments. The size of the buildings also meant that the simple ability to be able to call up a drawing when out on site has the potential to save significant time just in Construction Managers walking back to (and getting "stuck" in) the site office. "*Well from one end of the site to the other, you know you waste a good hour, two hours maybe… It's absolutely massive, you can get lost in it as well and once you get back to your office, you've got to sit down and catch up on your e-mails quickly before going back out*".

The construction management approach adopted on Hospital Project involves substantial on-site coordination and supervision by Contractor's staff (compared to a 'construction management' model of allowing trade contractors to manage their own coordination). Teams of Construction Managers are responsible for handing over spatially defined areas of floor, across work packages. "*So there is, therefore, an element of us acting as the Foreman in the field, … and sometimes these contractors, you know, were in effect co-ordinating where they work next week,… so having got the Tablets and the information, we then said, "Well these should be used for progress monitoring"*".

## 4.2. Innovation history

The adoption of BIM for design coordination was undertaken during the design phase of the project before any decisions had been made to use tablet PCs on site or to develop software to support site BIM usage.

> *"no one knew that back then, this is all served off the back of the work that was done in the early days so our mind set was, we are going to*

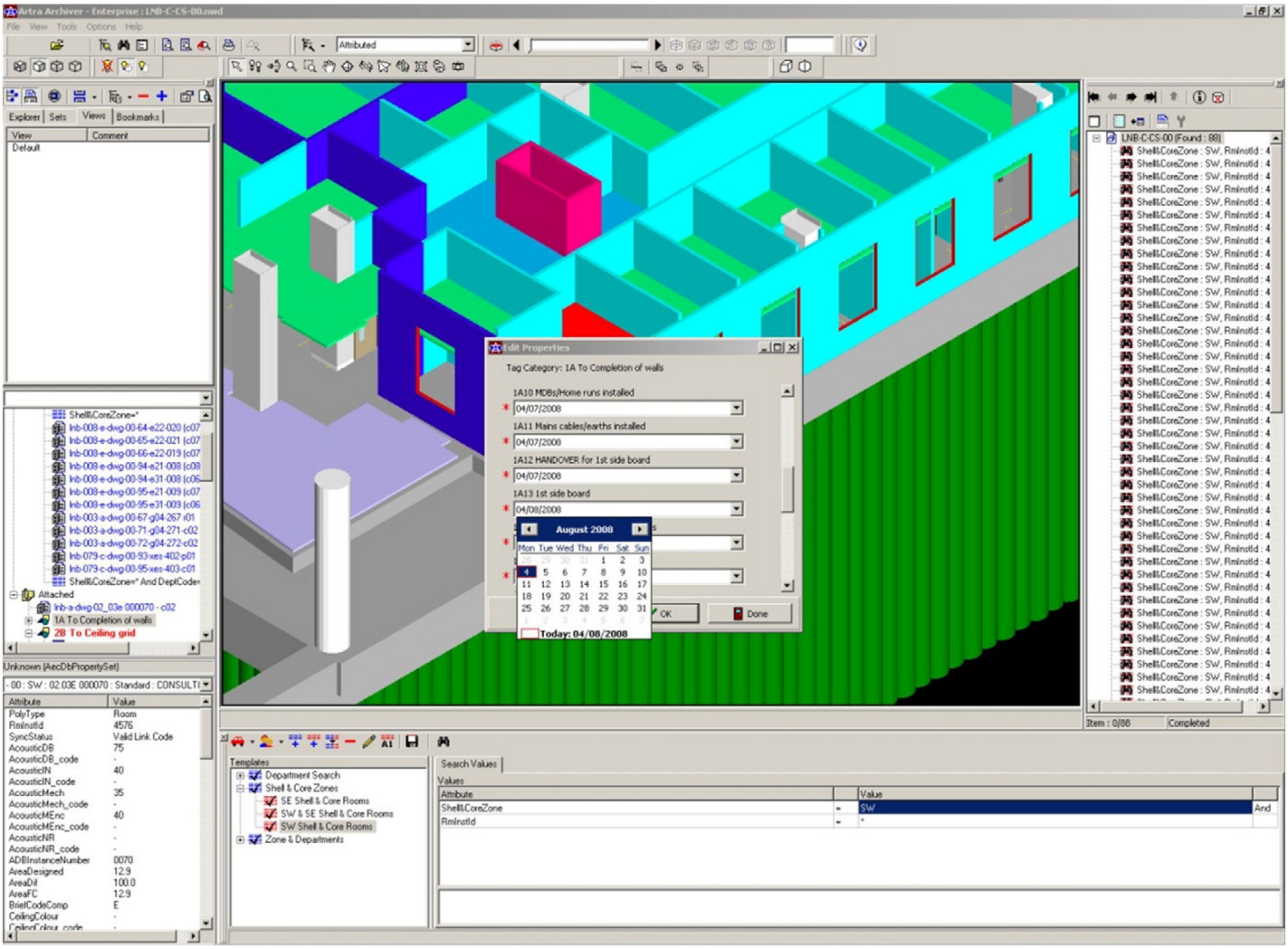


**Fig. 4.** Using 3D viewer and Site dBase to enter progress data for consulting room.

> *produce a 3D model, we are going to check it for compliance, we are going to clash detect it, we are going to convert it into 2D and then we are going to scrap it.*"

The use of tablet PCs and the development of site BIM systems are seen as building on the existence of the coordinated 3D models. The use of BIM for design had given the construction teams not only a "*great visual diagram*" but also "*information in the background that nobody knew about*".

The earliest event identified in the adoptions of tablet PCs was early in 2008, at the Contractor's worldwide R&D conference in London. Representatives of the North American business demonstrated tablet PC functionality that they had attempted to introduce at home. Following this a broad 'Handheld Computing Strategy' was agreed for the exploration of site BIM as a six month experiment to 'see how far it could go' and a BIM and 3D CAD Manager and a BIM Coordinator were employed by Hospital Project. The first phase of development was the DMS/Site dBase document link and the progress monitoring system, and the purchase of eleven tablets over the course of the year. In 2009 an additional twenty tablets were bought for Hospital Project, compliance functionality added and the defect system started. At the time of the research the defect system was complete but waiting for an issue of a link to the DMS defect system to be resolved — this has since been implemented. It is anticipated that technological development of the tablets will deliver more functionality (which in turn may place further demands on the underlying systems and processes in order to support them). The Hospital Project now has over thirty tablets, some bought as part of the normal PC replacement cycle allowing people to 'have their own' with the tablet and docking station replacing laptop or desktop PCs.

### *4.3. Implementation approach and practices*

The development effort to implement tablet PCs and site BIM systems on Hospital Project was lead by construction project office employees.

Particularly significant was the recruitment by Hospital Project of a BIM and 3D CAD Manager and a BIM Coordinator and the increasing involvement of Senior Document Controllers. This group made up a core team of Contractor's project office staff who took responsibility for delivering the technology and worked on BIM and tablet related systems more or less full-time.

> "*But its took a long time to get it because basically its been [BIM & 3D CAD Manager] who's now on board and really involved with it [BIM Coordinator, software vendor] and myself (Senior Document Controller) getting everything up and running and its, you know, we couldn't devote a serious amount of time to it at the start because we only had a couple of tablets but now everything is kind of flowing, the Directors have been really impressed with the tablets and can understand why we spend [money on the project].*"

A more peripheral group of actors also participated in the innovation process. These included those with responsibility for aspects of the construction project (e.g. Compliance Managers) who spent time on the BIM project because they saw it as a way of helping to achieve their business objectives and users who interacted with the innovation with requests, ideas or complaints that influenced the ways in which the innovation progressed. For example, the Environmental Manager and some Quantity Surveyors requested help in extracting quantities of materials from the building models for use in their own business processes. These were provided by querying functionality in Site dBase but, more importantly, the requests provided another idea of what BIM was 'for' and provided evidence of the usefulness and potential of the systems. The other significant group of project actors were the managers who approved and supported the innovation. Their role is discussed further in the later section covering the relationship between the project and the corporate IT department.

The development approaches described by our research participants were largely informal (by the standards of structured development methodologies) and incremental, probably best classified as a form of prototyping. The rollout relied heavily on individual innovation team members, their efforts and their relationships. Contractor only has one developer for its in-house DMS and Site dBase was developed by a very small software supplier with a handful of employees. The picture that emerges from the interviews is of a small group of people working very closely together to develop a shared idea of what was required. "*The [Site dBase] programmer with the [DMS] programmer, they can sit down, they've sat in this room many a time and coded out the requirements to get the portability onsite and all the documentation on site.*" Key to this was the personal trusting relationships between innovation team members and developers working sometimes without the knowledge or explicit approval of their parent organisations, "*it was happen[ing] because individuals were in the right place at the right time. It was all about creating relationships and getting people to do things that actually they hadn't told their superiors that they were doing*".

In addition to the development effort, the rollout required substantial investment of time in training and support. Participants emphasised the novelty of any forms of digital technology for many users; that, "*there's guys out there are still used to rolling up A3 drawings in the back pocket and then turning on a PC is quite a bit of fear for them actually*". The overall perception is that 'builders' as a group are not computer users, although adoption can be encouraged with appropriate support. This took the form of formal training, publication of self-help guides and one-to-one support and coaching. 'Training' wasn't a one-off event — ongoing support was needed not only to assist but also to 'bed-in' the use of the technology. "*We've got guys out there now who are 60 years of age . . .there's been a huge culture change … it literally has been walk around for three of four days, hold their hand*". The increased use of tablets by initially sceptical users is a source of some pride for the project team. *"They've not come from a computer background, they're all builders you know. So they are getting that level of support and now some of the guys, I mean there is one guy that couldn't switch a computer on and now he's a tablet super user, you know, whatever he's doing, he's got his tablet with him so its good to see people like that embracing the technology and understanding what it is so I think you know, a lot has changed in the last three years of this project."*

### *4.4. Relationship between Hospital Project and the central IT department*

The Tablet rollout and Site-BIM developments are clearly described as a Hospital Project innovation. The importance of the small group of project actors has already been described. The involvement of the firm's central IT function ('IT') appears to have been limited. Even where acknowledged (e.g. work by the in-house DMS developer) this is presented as based on personal efforts and relationships in spite of, not due to, central IT support.

> "*Well what we did, we just employed Site dBase and it sort of came out of the Hospital Project budget and IT just helped out where they can and you know its not going on their server but it now it is on the actual server, so they are now getting a bit more relaxed with Site dBase*"

There was even some concern that innovation was hampered by IT "*this is a perfect bit of software but IT have to approve it, it has to go through about a year of test before they say yeah, that's the one*". More broadly, IT don't understand what's required on site. "*A lot of the issues we've had with the Tablets is the IT Department set them up to a working format and because they're detached from the site, it's — they need to come out to site more often to actually get… what they need on the site works 'cause they're just stuck back at [head office]*". It is acknowledged that IT do not have the capacity to make changes required across many construction projects, often requiring projects to develop their own ad-hoc, solutions. Central IT are seen more as a barrier to be overcome than a source of support: "*they will put their feet down, saying no you're not doing this when everyone says that's the way forward but IT but you know they have to approve everything and sometimes it's very frustrating*".

The implication of this is that the innovations were dependent on being able to acquire enough resources and local power to circumvent 'the system'. Key to this is the approval and support of local project directors: "*With this project our director… he's given us the go ahead for us to say right IT, you can be involved but we are going down the Site dBase route*". The resources necessary for the developments came mainly in the form of project staff to work on the implementation (described earlier) as well as project budgets allocated to hardware and software costs. The increased use of technology for information management has meant that the role of Document Controllers has expanded into a "*sub-IT Department function*". The only resources external to Hospital Project have been development support from one DMS developer from Contractor's IT department and from the Site dBase supplier — itself only consisting of a handful of people at the time. In Section 4.3 we described how development effort was sometimes 'unofficial' — motivated by personal relationships and intrinsic interest rather than formally allocated and supervised work tasks. An example of this is the organisation of the coding of the interface between DMS and Site dBase:

> "*so it was [Developer] from [Site dBase supplier] who wasn't telling [his manager] what on earth he was doing. He was just coming down here "oh I've just got to pop down to [Hospital Project]… they've asked me to come and check the server they've got issues with it" and he was coming and developing… and then we've got [Developer] off the [DMS] team, "oh, ok I'll do that. Don't say any.. don't tell [my manager] that I'm doing this", y'know. Because they were actually.. it was something that was a bit of interest y'know, it was real*".

The unofficial nature of the development projects did make them partly reliant on personal relationships, vulnerable to prioritisation of official work and they were presumably running at risk of being cancelled at any time (although sanctioned IT projects are hardly immune from this). The implementation had, "*some real successes and we moved rapidly forward but because it was never planned it was often we (BIM Manager and Document Controller) would be waiting for several weeks waiting for something to be done… and not being really in a position to say "look, can you make it a priority?" Cos it isn't. [the Developers would say] "I shouldn't really be doing this. I'm doing it as a favour.""*"

However, there is a clear narrative that the informality and small scale of the development was crucial to the success of the innovation. "*We'd never been in the position we are now had we not had [internal DMS system] on this project. Had that been something like [a large DMS database provider] and we'd have had to go off to [get] the costs involved… we would never have got to where we've got because the costs would have been a — there would have been an alarm bell ringing in the first instance.*" Our analysis is suggesting that the implementation projects had just enough resources to achieve something but few enough that they were able to stay 'under the radar' until they could demonstrate benefits. For the developers, "*the point where it became obviously a successful, y'know, implementation… they were then able to show… tell [their managers] what they'd been up to*".

## 5. General discussion

Implementation and use of BIM on Hospital Project is ongoing, the construction phase is continuing and the operation and maintenance phase has not started. This paper has focussed on a specific time and purpose of the BIM implementation — technology developments during the construction phase to support site operations. We have focussed on the implementation of the technology and have sought to provide an account of that effort. In the rest of the paper we reflect on three general themes that we draw from our research: the way in which the implementation team talk about the success of the innovation; its emergent quality; and the importance attributed to its project-led nature.

### 5.1. A successful implementation

Contractor's BIM Managers have attempted to measure the benefits of the BIM implementation and have conservatively identified a number of returns on investment including; waste reduction, a lower than usual cost growth in packages for service installation, and significant savings in spending on administrative and coordinating staff time. In our primary data however, our research participants regard the Site BIM implementation project as successful because the technology was approved, delivered, adopted by site users and found to be useful.

> "*My responsibility was making sure or trying to do whatever I could for the man at the sharp end to have the latest correct information. So, when I got to a point where we've got a Tablet that delivered the latest information, I was just delighted*".

This finding of the local and fluid way in which agreement about project success is established is consistent with some streams in the project management literature. Much project management practice and research defines success in terms of projects proceeding to plan to deliver against pre-established time/cost/quality criteria. However, research has shown that project participants apply other behavioural or organisational criteria and that these vary along the course of the project lifecycle [22]. For example, in one study of major infrastructure projects [18], participants assessed project success not only in terms of cost, time and technical performance but also the nature of project management inputs and experiences on the project (more specifically the absence of negative experiences).

On the Hospital Project BIM implementation, in addition to technology delivery, success was discussed in terms of the degree of take-up. Tablets are perceived to have been key to driving the use of BIM and project data more broadly as well as streamlining day-to-day work and allowing construction managers to be on site where "*they should be*". The emphasis on the importance of site work highlights the fact that Site BIM is seen more as a tool to support and partly automate existing processes and practices rather than transforming them by, say, making site intervention less necessary. This is consistent with the findings of a survey of managers in large construction contractors that measured the perceived importance of a number of reasons for the use of IT. "Reduced unnecessary site visits" was the lowest scored item of thirty indicators and such an outlier that it was dropped from further analysis [23]. Our interpretation, supported by this research, is that reducing site visits isn't just seen as a very weak benefit of IT in construction but it is not even an objective. In the case study, the purpose of the IT innovation was to keep people on site and to reduce unnecessary visits to the office.

This adoption context and set of users means that it is very important that technology and systems are easy to use, help users to achieve recognisable business tasks efficiently and that they actually work: "*they don't want to be storming up and down the building, from the tenth floor [laughs] back into the office, you know, a couple of times a day because their machine's not working and it's not what they want. They want — if it works, yes, they don't want it not working, you know*". This characterisation of site users' attitude to new technology supports Jacobsson and Linderoth's [17] finding that there is a distinct construction project 'frame of reference' for ICT adoption that favours immediate efficiency benefits for any technology introduced.

### 5.2. An emergent implementation

The accounts given of the Site BIM implementation give a picture of the emergent and dynamic nature of the 'innovation journey' [24] undertaken by the project team. The first step on that journey appears to have been to regard the 3D information as an exploitable resource that can be used to support site operations. Even in retrospect though there appears to have been multiple ideas as to what the nature of that support should entail. So, for example one participant stated that the intention for the tablets was to simply get correct, usable information to site users without any particular exploitation of the data. Another idea was that using tablet PCs for monitoring progress and compliance was the driver and the information function arose out of that. In another account the purchase of the software that allowed the 'site BIM' functionality was originally motivated solely to produce electronic handover documentation.

This emergent strategy is in contrast to the usual advice that "successful implementation of new and innovative Information Technology (IT) and Information Systems (IS) in construction requires the development of strategic implementation plans prior to IT/IS project commencement" [25]. The gradual rollout of the numbers of tablets reflects the experimental and exploratory nature of the development of the BIM systems on Hospital Project. An initially small number of tablets and working underlying systems (otherwise restricted to people's desktops) provided the confidence to purchase additional tablets which in turn created a demand for the development of additional functionality. These technological relationships also interacted with organisational factors. So, for example, the business strategy to let small site work packages and get value from expertise in management created a requirement to support progress monitoring that the Tablets and emerging Site dBase were equipped to deliver. The resulting changes in practices are expected to subsequently increase the number of tablet users which is likely to drive further systems development and so on. This account of the unfolding interactions between Tablet PCs, software systems, users and system developers draws on and contributes to a growing body of research in construction that analyses technology not just as the outcome of innovation processes but as an active shaper of those processes [16,26,27]. The idea that technology can affect people, organisations and behaviour is central to the application of ICT to construction and forms the basis of the business case for most technology-enabled change projects. Analysis of ICT implementations should recognise that technology affects its developers as well as those labelled 'users' (for a theoretical discussion of these issues see [16,26]).

The emergent nature of the implementation is consistent with other longitudinal accounts of innovation developments [24]. As such, it is not possible to attribute this to either the construction project context or the technology deployed. The Site BIM implementation did involve significant software development and further research including the implementation of more stable technologies into similar settings would help our understanding of these issues. In the meantime, we suggest that it is important for technology vendors and brokers to be aware of the possibility of this emergent informality in development when engaging with construction projects to deliver technology.

### 5.3. A project implementation

Contrary to Winch's [14] assertion that, in construction, firms adopt innovations and projects implement them, in this case the development of Site BIM and the tablet rollout was a project innovation. This is both an analytical finding in our research and a reflection of the real sense of ownership among the Hospital Project team. The, project-adopted, Site dBase is; new, helpful, ours, optional, and the future. The in-house corporate DMS is; clunky, difficult to use, and imposed. The site exploitation of BIM is via tablet PCs and Site dBase — technologies that the project developed independent from and in spite of Contractor corporate IT.

The limited role of the firm's central IT department reflects the project-lead nature of the innovation. This is not uncommon in construction organisations: "because project teams are often self-contained, they may draw little from central services" [15]. The innovation project's status relative to 'official' IT programmes is likely to have contributed to its freedom to emerge and develop over time and also for the informality of the development methods used. Rarely mentioned by our participants, but perhaps significant here, is the large size of the project. Large organisations, including temporary project organisations, typically have more slack resources than smaller, allowing the space and scope to experiment and innovate [28]. The project-centre relationship identified here might in fact be an issue of relative size and power rather than a structural issue.

The importance of resources for innovation can be seen in the employment of specific people with a mandate to develop 'BIM' on the project and the existence and subsequent involvement of the sizeable Document Controller teams allowed people to develop roles that included a project-specific IT capacity which supported subsequent developments. The importance that participants attributed to the existence of this core team is also consistent with research findings on the importance of technically competent innovation champions [29]. As well as the core team though, a wider network of people were involved. Interested users and managers with specific data needs were a source of requirements and provided evidence for project demand for the system. Local project Directors approved the implementation, provided resources and gave the innovation legitimacy.

The reasons stated for the development of Site BIM on the project were similarly project-specific: the existence of design-phase coordinated 3D models; the scale and speed of construction; and the retained responsibility for site management and work coordination. The latter seems particularly significant given Sacks et al.'s [4] argument that the relative neglect of site production management tools in the BIM universe is due to the reduced attention paid to site production management by main contractors adopting "hollowed-out" model of reduced staff and trade subcontracting. Further research on the different IT strategies and IT practices of projects and firms adopting a variety of organisational and management and supervision arrangements would be valuable for advancing our understanding of these relationships. A fruitful line of inquiry here would be to select and analyse cases using the two dimensions of 'project autonomy' and 'stakeholder complexity' proposed by Artto et al. [30]. The empirical findings of the relationship between Hospital Project and Contractor, as highlighted by the Site BIM implementation shows that it is important to distinguish between the project and the permanent organisation when analysing ICT adoption in the construction industry [17]. Further exploration of the project-firm dynamic could also contribute to Engwall's [18] call to move beyond a 'lonely project' perspective by analysing projects in their historical and organisational context.

## 6. Conclusions

The business case for the Hospital Project Site BIM implementation was based on not only specific features of the construction project but also implicit assumptions about the nature of the industry and its work. The development and rollout was delivered by a small team of construction project staff and enrolled IT personnel using informal methods and strong personal working relationships. The current state of the innovation emerged from the practices and changing context — the introduction of Tablet PCs into the innovation network was pivotal in determining the shape of the systems and processes developed. The Site BIM implementation was judged by participants to be successful and significant in scope and ambition for the current UK construction industry. It was also described as strongly project-based and project lead. The implementation included not only elements of straightforward technology adoption but also new technology development and process and organisational changes. The implementation was emergent and exploratory and, while Site BIM remains a technology in the process of being established, we would predict that this would be the same for other projects. Our findings on the roles of the construction project and the parent firm provide a counter-example [20] to the idea that it is always firms that adopt innovations and then apply them on project. Future research could help our understanding in this area by directing attention to the process and context as well as the content and outcomes of similar construction IT innovations undertaken across a variety of project and organisational arrangements.

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